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EFFECT OF METHANE ON THE VISCOSITY OF WATER

*University of Alaska, Fairbanks*

M.S. 1985

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**EFFECT OF METHANE ON THE VISCOSITY  
OF WATER**

**A  
THESIS**

**Presented to the Faculty of the University of Alaska  
in Partial Fulfillment of the Requirements  
for the Degree of**

**MASTER OF SCIENCE**

**By  
Abdolkarim Bloori B.S.**

**Fairbanks, Alaska**

**September 1985**

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EFFECT OF METHANE ON THE VISCOSITY  
OF WATER

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## ABSTRACT

Viscosity of water is an important variable used in modeling the flow of fluid in a reservoir. Thus, it is necessary to know its viscosity at reservoir condition.

Correlations are available in the literature for the prediction of water viscosity as a function of temperature, pressure, and salinity. Despite the fact that methane is soluble in water to some extent, little useful data have been published regarding the effect of dissolved gas on water viscosity.

In the current work, a rolling ball viscometer was modified to measure the viscosity of an electrolyte solution. Then, it was used to measure the viscosity of methane-saturated water at 100, 150°F, over a saturation pressure range of 0-7000 psi.

The viscosity was found to increase by up to 6% with gas saturation over the above pressure-temperature range. A correlation of these data, and suggestions for extension of this work are presented.

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## CHAPTER 1

### INTRODUCTION

Viscosity is an important variable required for modeling the flow of fluids in a reservoir. Normally, oil and gas are the mobile phases of interest. However, there are cases in which water is a mobile phase. Thus, it may be necessary to know the viscosity of water at reservoir conditions. In particular, water viscosity is an important factor for prediction of production from geopressured aquifers.

Several variables affect the viscosity of water. These variables are temperature, pressure, dissolved solids content and dissolved gas.

The viscosity of pure water as a function of temperature and pressure is available in the literature. A correlation also exists for the prediction of water viscosity as a function of temperature, pressure, and dissolved solids content.

Moszynski (1) measured the viscosity of water and steam using an oscillating sphere. The pressure and temperature ranges of his experiments were 44 to 4996 psia and 86 to 367°F. Nagashima et al. (2), measured the viscosity of water and steam at temperatures of up

to 1652 F and pressures up to 14504 psi. Numbere (3) has published a review of the data on water viscosity and report a good agreement between the data on the viscosity of water published by Moszynski (1), Bruges et al. (4), and Nagashima et al. (2).

The viscosity of water at temperatures in the range of 32 to 1500°F and pressures from 15 to 12000 psi is conveniently tabulated in the Steam Tables (5).

Considerably less data is available on the viscosity of brine at reservoir conditions. Stanley and Batten (6), Isdale and Morris (7), Chen et al. (8), and Ershaghi et al. (9) have published data on brine viscosity.

Stanley and Batten (6) used the rolling ball viscometer to measure the viscosity of sea water (19.37 % chlorinity IAP0 and 35 % salinity) at 32 to 86°F and up to 20,000 psi. Isdale and Morris (7) measured the viscosity of sea water with salinities up to 15% by weight at 68 to 356°F. They used the master viscometer for temperature ranges of 68 to 167°F and a pressurized falling body type viscometer thereafter. Chen et al. (8) also measured the viscosity of sea water (11% salt) from 32 to 392°F. Ershaghi et al. (9) used the capillary tube viscometer to measure the

viscosity of brines consisting of sodium chloride, potassium chloride, and calcium chloride. The salinities of the brines were from .99 to 16.667 % by weight. Their experiments were conducted at temperatures up to 527°F.

Numbere (3) has published a review of the physical properties of reservoir brines. Equation 1-1, taken from that work, may be used to calculate the effect of sodium chloride concentration on the viscosity of brine.

$$\frac{\mu_{\text{brine}}}{\mu_{\text{water}}} = 1.0023 + (6.508 \times 10^{-3}) \times S + (8.32 \times 10^{-4}) \times S^2 + [0.13 + (0.872667) \times S - (2.7182) \times S^2] \times 10^{-4} T - 0.09 \times 10^{-6} T^2 \dots\dots\dots (1-1)$$

It is known that methane will dissolve in water to some extent. The solubility of methane in water at various temperatures and pressures was determined by Culberson and McKetta (10). Their results are summarized in Figure 1-1.

Blount et al. (11) have indicated that the solubility of methane in water depends on salinity, in addition to pressure and temperature. The amount of gas in the solution decreases with an increase in the dissolved solids concentration and temperature and decreases with an increase in pressure.

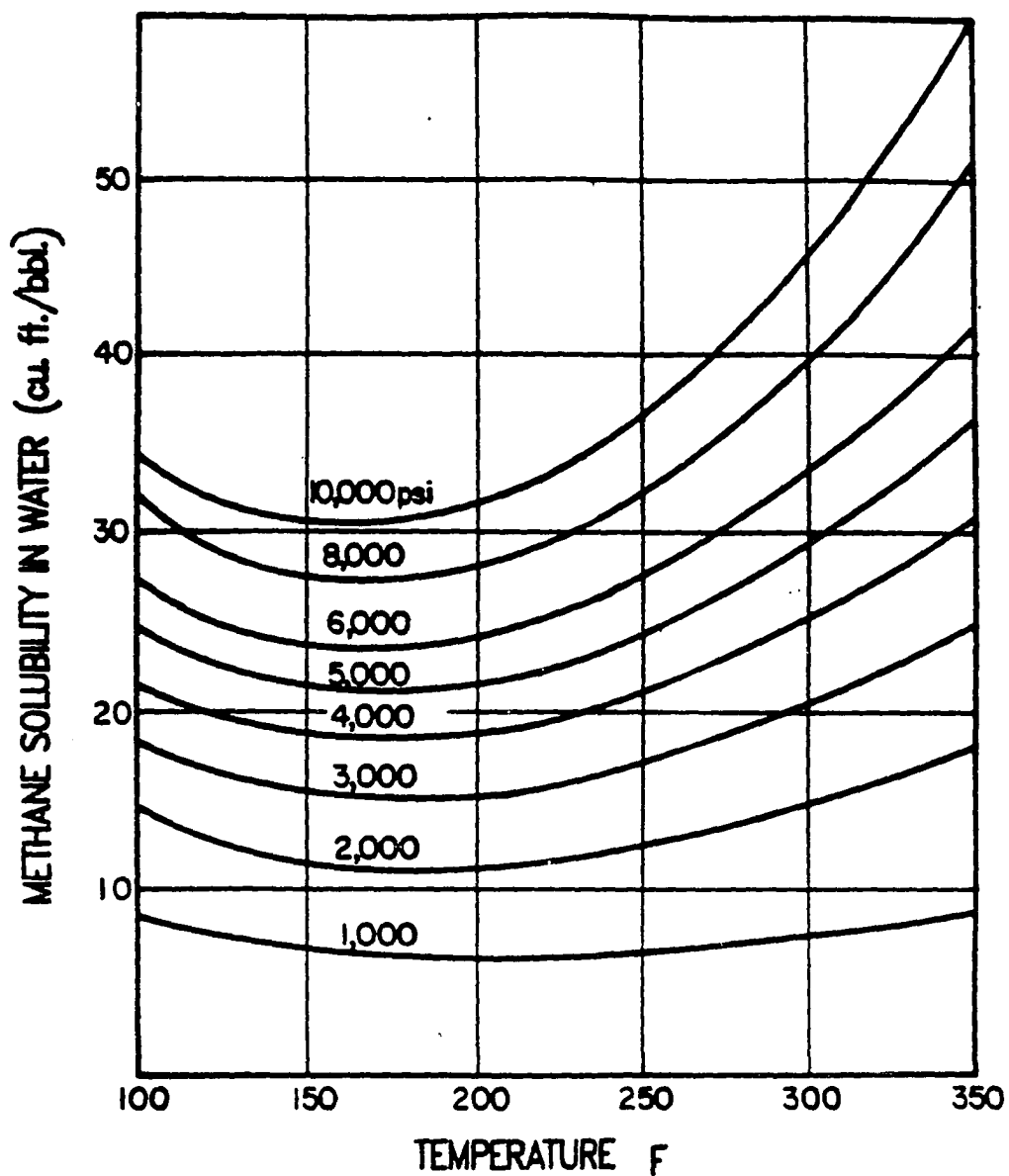


Figure I-1: Solubility of Methane in Water (After Culberson and McKetta (10) ).

Jones (12) developed an empirical equation to determine the effect of salinity on the solubility of natural gas in water. Equation 1-2 (After Amyx et al. (13)) taken from Jones work, may be used to calculate the solubility of natural gas in brine.

$$R_{swb} = R_{sw} \left( 1 - \frac{C \times S_1}{10,000} \right) \quad \text{..... (1-2)}$$

The value of correction factor C, which is depend on the temperature of the water, is shown in Table 1.

TABLE 1

Correction Factor After Amyx et al.(13)

Temperature °F	Correction Factor C
100	0.074
150	0.050
200	0.044
250	0.033

For this study, it was necessary to have accurate data on the density of gas saturated water.

Dodson and Standing (14) reported formation volume factors for gas saturated water. An interesting finding was that volume of gas saturated

water at 3000 psi is less than at 2000 psi, although the fluid at higher pressure contains more gas in solution. Thus, the decrease in volume due to the compressibility of water exceeds the increase in volume due to dissolved gas. The results of Dodson and Standing paper is summarized in Table 2.

TABLE 2  
Formation Volume Factor for Natural  
Gas Saturated Water after  
Dodson and Standing (14)

Saturation Pressure psia	Gas Formation Volume Factor, at °F			
	100	150	200	250
1,000	1.0045	1.0183	1.0361	1.0584
2,000	1.0031	1.0168	1.0345	1.0568
3,000	1.0017	1.0154	1.0330	1.0552
4,000	1.0003	1.0140	1.0316	1.0537
5,000	0.9989	1.0126	1.0301	1.0522

A thorough examination of the literature revealed only three references for viscosity measurements of water containing a gaseous component.

Caw and Wylie (15) measured the viscosity of air saturated water relative to air free water at 68°F and atmospheric pressure. They reported that the effect of air on the kinematic viscosity of water at atmospheric pressure was not in excess of 0.013%. Kestin and Whitelaw (16) used the oscillating sphere viscometer for the same purpose. They reported that air does not have any effect on the water viscosity.

Rockare and Randolph (17) demonstrated the use of the capillary tube viscometer to measure the viscosity of brines. They attempted to measure the viscosity of methane saturated water with their apparatus, but had difficulties with the equipment and discontinued the project. They concluded that dissolved gas probably had a small effect on viscosity, but were unable to quantify that effect.

## 1.1 PURPOSE AND SCOPE

Viscosity is a key variable to consider in the flow of fluids through porous media. Correlations are available for prediction of water viscosity as a function of temperature, pressure, and dissolved solids content. While it is known that natural gas (methane) does dissolve in water to some extent, data



are not available on the effect of dissolved gas on water viscosity. Due to the lack of data for the viscosity of gas saturated water the effect has been ignored. It is reasonable to assume that the viscosity of methane saturated water may vary. This could result in significant errors in flow calculations related to water.

The purpose of this work is to modify a standard Ruska rolling ball viscometer and to measure the viscosity of methane saturated water.

The pressure and temperature ranges of the experiment were from 500 to 7000 psi and 100 and 150°F. The viscosity of the samples was measured at their saturation pressures.

## CHAPTER 2

### 2.0 ROLLING BALL VISCOMETER

#### 2.1 THEORY OF OPERATION

##### 2.1.1 Basic Principle

The rolling ball viscometer consists of an inclined tube, which is filled with the fluid whose viscosity is to be measured. A ball rolls down the inside of the tube (see Figure 2-1 ). The terminal velocity of the ball is a function of the fluid density and viscosity. The time the ball takes to roll from the top of the tube to the bottom, which is related to the terminal velocity of the ball, can be measured accurately. The viscosity of the fluid is related to the roll time by the equation:

$$\mu = K t(\rho_{\text{ball}} - \rho_{\text{fluid}}) \quad \text{..... (2-1)}$$

The viscosity of the fluid is directly proportional to the roll time of the ball and the density difference between the ball and the fluid (buoyancy effect).

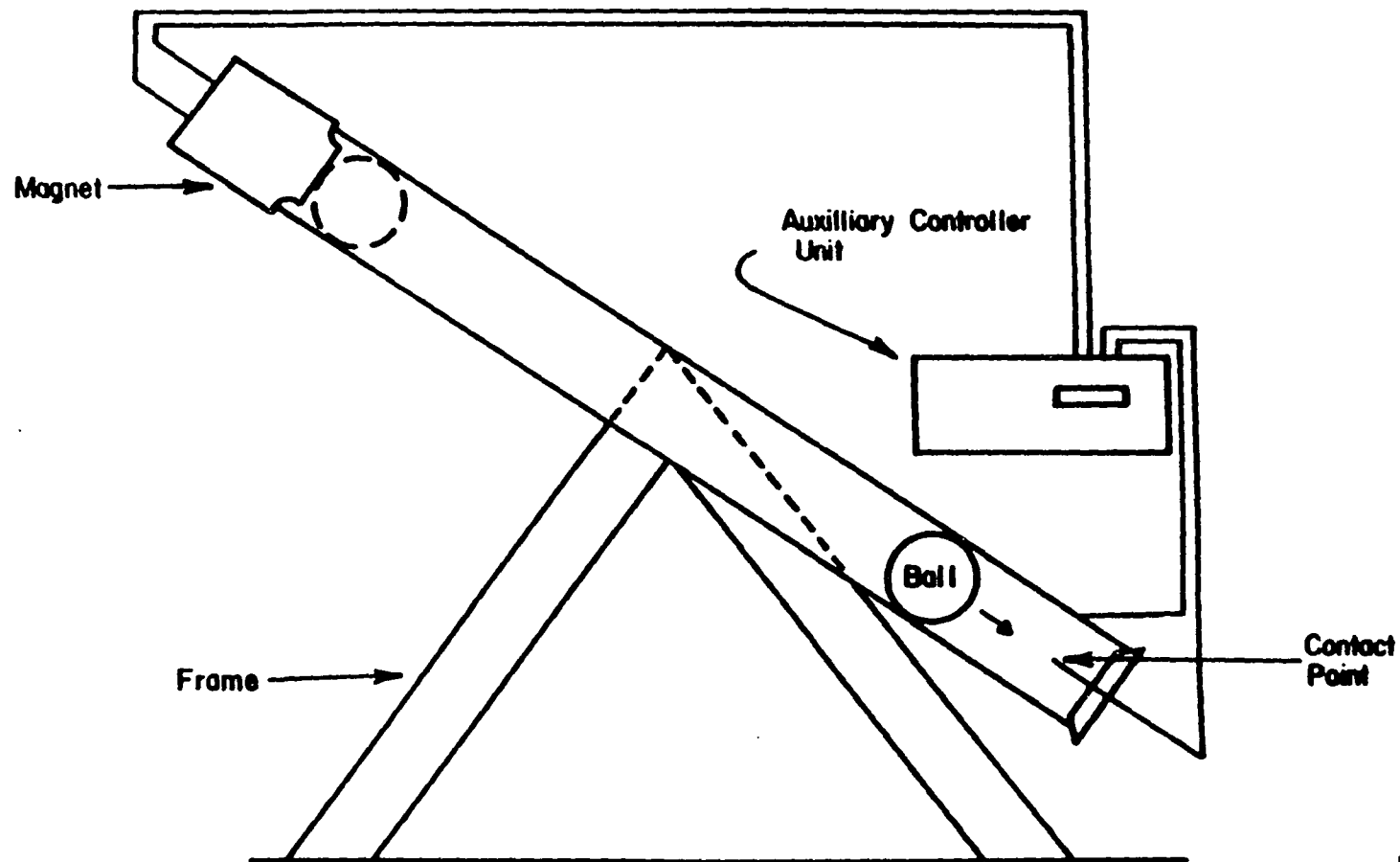


Figure 2-1: Schematic Diagram of Rolling Ball Viscometer.

Several authors have published papers on the theory and operation of the rolling ball viscometer (18-20). Flowers (18) was the first to use the inclined tube and rolling ball as a viscometer. It was then studied by Hersey and Shore (19) who used Equation 2-2 to calibrate the viscometer.

$$K \frac{\mu}{\rho_{\text{fluid}} \sqrt{\frac{\rho_{\text{ball}}}{\rho_{\text{fluid}}} - 1}} = t \sqrt{\frac{\rho_{\text{ball}}}{\rho_{\text{fluid}}} - 1} \dots\dots\dots (2-2)$$

This relation is linear for low velocities. Later, Sage (20) measured the viscosity of a hydrocarbon liquid using simplified form of Equation 2-2 similar to Equation 2-1.

It has been shown by Hubbard and Brown (21), that the operating range of the rolling ball viscometer depends upon the critical Reynolds Number for the apparatus. The critical Reynolds Number is dependent upon the ratio of the ball diameter to the tube diameter (see Figure 2-2). As this ratio increases, the critical Reynolds Number of the apparatus increases. For a Reynolds Number less than 20, a plot of viscosity versus the product of the roll time and the fluid-ball density difference is linear. From this relationship a calibration equation, in the form

of Equation 2-1, can be developed.

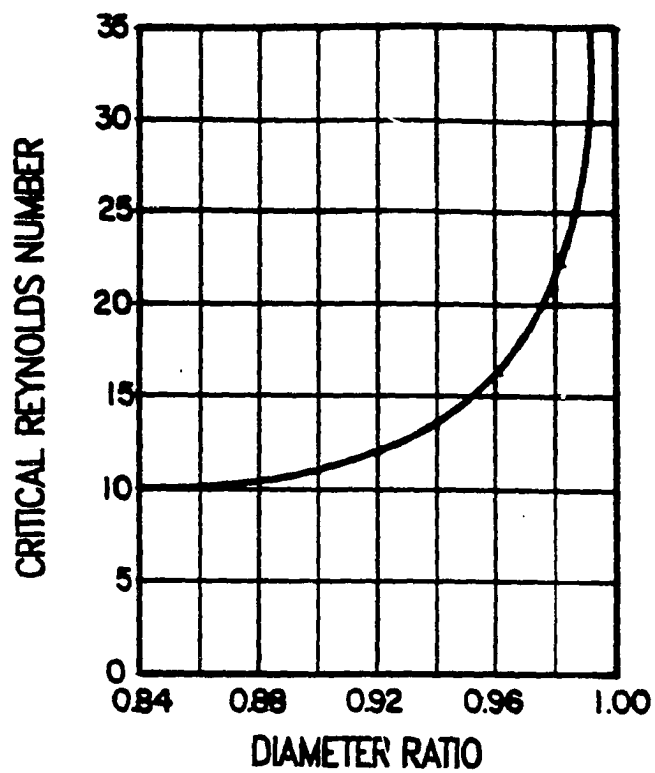


Figure 2-2: Critical Reynolds Number for Rolling Ball Viscometer (After Hubbard and Brown(21)).

To determine the coefficient  $K$  in Equation 2-1, the viscometer should be calibrated with fluids of known viscosities and densities. Moreover, it is better to use several fluids of known viscosity and density which have similar properties to the "unknown fluid" to provide a good calibration in the viscosity range of interest.

## 2.2 MODIFICATION OF THE VISCOMETER

With the rolling ball viscometer some method must be used to determine the velocity of the ball. With the Ruska viscometer an electrically controlled timer measures the time required for the ball to roll down the length of the tube. At the top of the tube an electro-magnet holds the ball. At the bottom of the tube there is a contact needle which is electrically insulated from the rest of the instrument (see Figure 2-3). The needle and the body of the viscometer act as the two terminals of a switch. When the ball reaches the bottom of the tube it makes contact with the needle in the tube and completes the circuit, tripping the timer. The clock starts when the ball is released from the magnet.

This method works well with nonconductive fluids. In the case of conductive fluids, such as brine, the electrical circuit is always complete, and can not be used to detect the arrival of the ball. To overcome this problem several designs were considered. These designs were as follows:



### 2.2.1 Resistivity-Conductivity Measuring Device

An attempt was made to detect the arrival of the ball by measuring the change in the current flowing through the circuit at the time the ball reached the bottom of the tube. Initially, the current flowing through the circuit is governed by the resistance of water  $R_1$  (Figure 2-3 ). When the ball shorts the circuit, the current changes because of the difference between the resistance of the ball and the fluid. The resultant circuit is shown in Figure 2-4 . Here,  $R_2$  is the resistance of the ball.  $RC_1$  and  $RC_2$  are the contact resistances between the ball and the needle, and the ball and the tube respectively.

To detect the change in current, a digital multi-meter was installed in the circuit as shown in Figure 2-5. After operating this modified version of the Viscometer for some time, it was found that there was no change of current through the circuit when the ball reached the bottom of the inclined tube.

The apparatus was then disassembled for inspection. It was found that there was severe corrosion at the point of contact between the ball and the needle (resistance  $RC_1$ ).

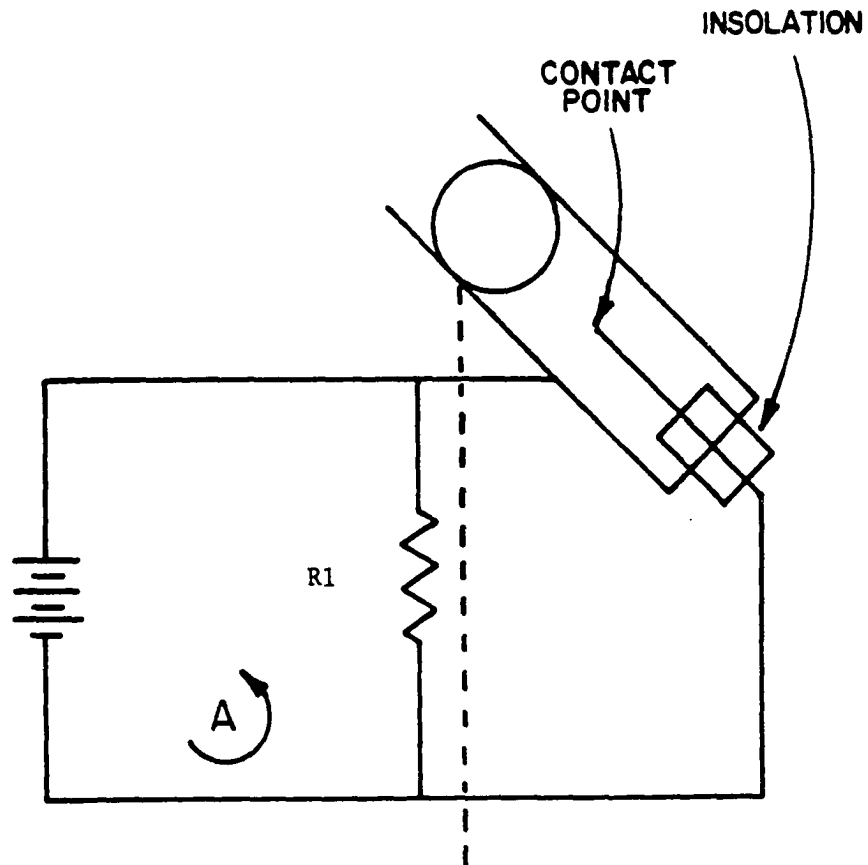


Figure 2-3: Schematic Diagram of C.R. Circuit before the ball reaches the contact point.

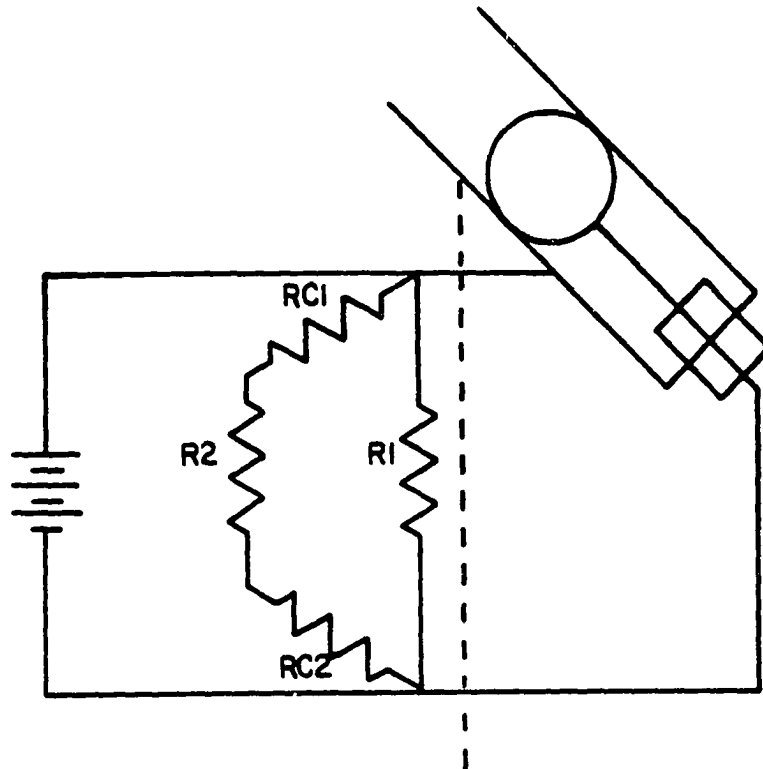


Figure 2-4: Schematic Diagram of C.R. Circuit after the ball reaches the Contact Point.

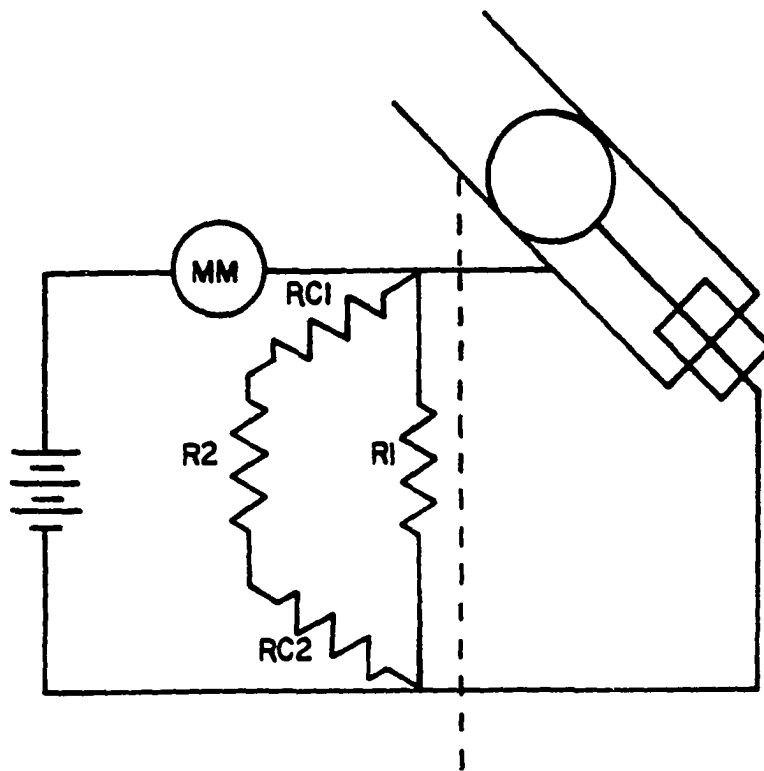


Figure 2-5: Schematic Diagram of C.R. Circuit and MultiMeter after the ball reaches the Contact Point.

To overcome this problem, the current was changed from a Direct Current to an Alternating Current, and the test was conducted again. Unfortunately, the same problem recurred. After checking for damage to the apparatus, it was found that there was a deposit of iron oxide present at the ball and needle contact point.

#### 2.2.2 Induction Coil

A test was made to determine the feasibility of sensing the presence of the ball using an induction coil. This was done by placing two coils, L1 and L2, around a glass tube. The coil L1 was used to generate a magnetic field by passing a constant current through it. Coil L2 was used to read the change in the magnetic field when the ball reached the bottom of the tube. To observe this change, coil L2 was connected to an oscilloscope as shown in Figure 2-6.

Initially, the coil L2 read a constant magnetic field. Arrival of the ball, at the bottom of the tube caused a change to the lines of flux generated by coil L1, and hence, a change of magnetic flux was detected by coil L2.

When the glass tube was replaced with metal, no change in the magnetic flux in coil L2 was detected. The metal tube acted as a shield and did not allow magnetic flux to pass through.

Next, an attempt was made to detect the arrival of the ball by putting a small permanent magnet at the end of two rods and wrapping a coil around these rods as shown in Figure 2-7. When the ball touched the other end of the rods, a sharp change in the magnetic flux resulted in an induced current in the coil, which was detected by an oscilloscope. This method could not be used because of the strong magnetic field generated at the bottom of the tube, which interfered with the free roll of the ball.

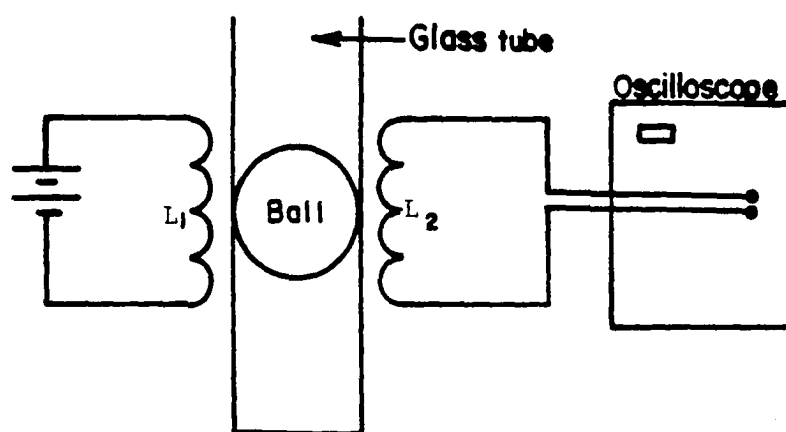


Figure 2-6: Schematic diagram of Induction Coil.

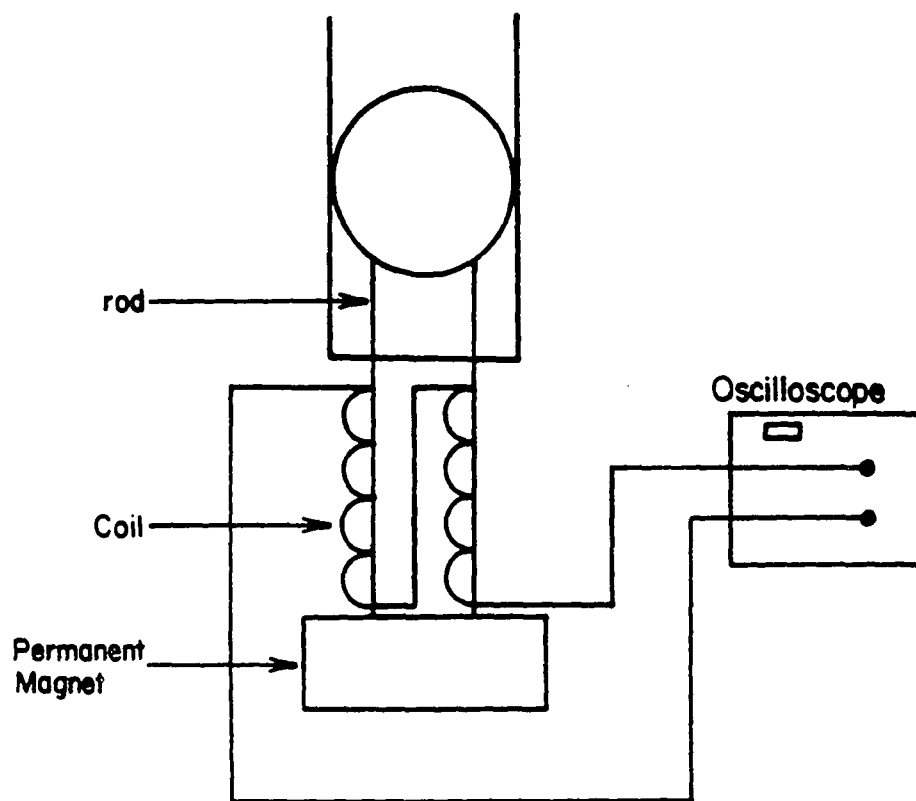


Figure 2-7: Schematic diagram of permanent magnet.



### 2.2.3 Proximity Sensor Device

Next, a proximity sensor was used to detect the arrival of the ball at the bottom of the inclined tube. The variation of impedance caused by eddy currents induced in a conductive metal target, is the working principle of a proximity sensor. The proximity sensor is an unique device because the target does not need to touch the face of the switch. In addition a non-conducting medium can also be placed between the sensor and the metal target. Another unique feature of the proximity sensor is that its response to ferrous material is approximately three times greater than nonferrous material. It was anticipated that the response of the proximity sensor could be used to stop the timer, and thus detect the arrival of the ball at the bottom of the inclined tube.

Several three wire Direct Current sensors model PK 82750 (Honeywell) were used in this experiment. The sensor was tried at atmospheric conditions and in the presence of salt water. The sensor spotted the arrival of the ball as indicated by a clear shift in the line seen through the oscilloscope. A shield of non-conductive material (epoxy), with a thickness of

0.02 inches, was placed on top of the sensor. The sensor worked fine with the epoxy shield in place. Next the sensor was placed in a metal casing lined with epoxy as shown in Figure 2-8, to test it at the pressure and temperature of interest. Initially it was tested for pressures up to 10,000 psi and room temperature. It worked fine. When the temperature was raised to 100°F the epoxy failed at a pressure of 1000 psi.

The Devcon Corporation recommended their high temperature mold maker which is rated at 36,000 psi and a temperature of 500°F. This material was used for mounting the sensor. The sensor was then tested at the pressures and temperatures anticipated in the experiments. However, no response was observed from the sensor. The unit was then disassembled and checked for possible damage. It was found that the sensor itself was broken. The sensor was probably damaged during the high temperature curing process carried out when the temperature was raised to 400°F and maintained for 3 hours.

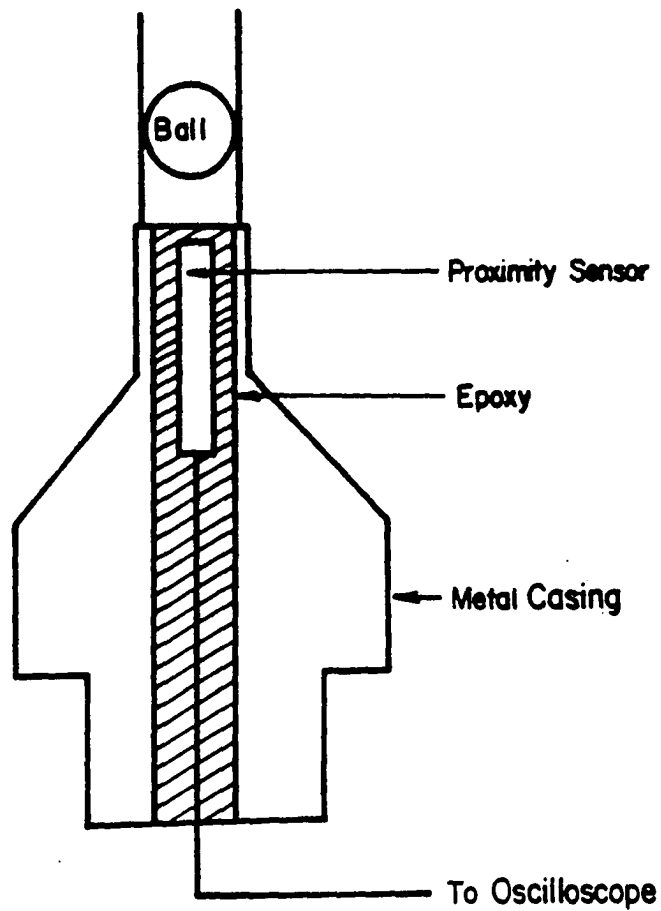


Figure 2-8: Schematic Diagram of Proximity Sensor Device.

#### 2.2.4 Audio Ball Detection Unit

When the ball arrives at the bottom of the tube, a small vibration results. If the room is very quiet and the velocity sufficiently high, the sound is audible. The sound can be picked up with a microphone, amplifier, and used to stop the clock.

A device was designed to detect the arrival of the ball at the bottom of the inclined tube using this audio principle. A diaphragm was designed as shown in Figure 2-9. One side of the diaphragm was attached to the end of the tube and the other side was placed outside the apparatus. A microphone was placed touching the outside face of the diaphragm. When the ball hit the bottom of the tube the sound waves travelled through the diaphragm and were picked up by the microphone. This sound was then sent to two amplifiers. The output from the amplifiers was used to operate a one-shot relay to stop the timer. The wiring diagram of this device is shown in Figure 2-10.

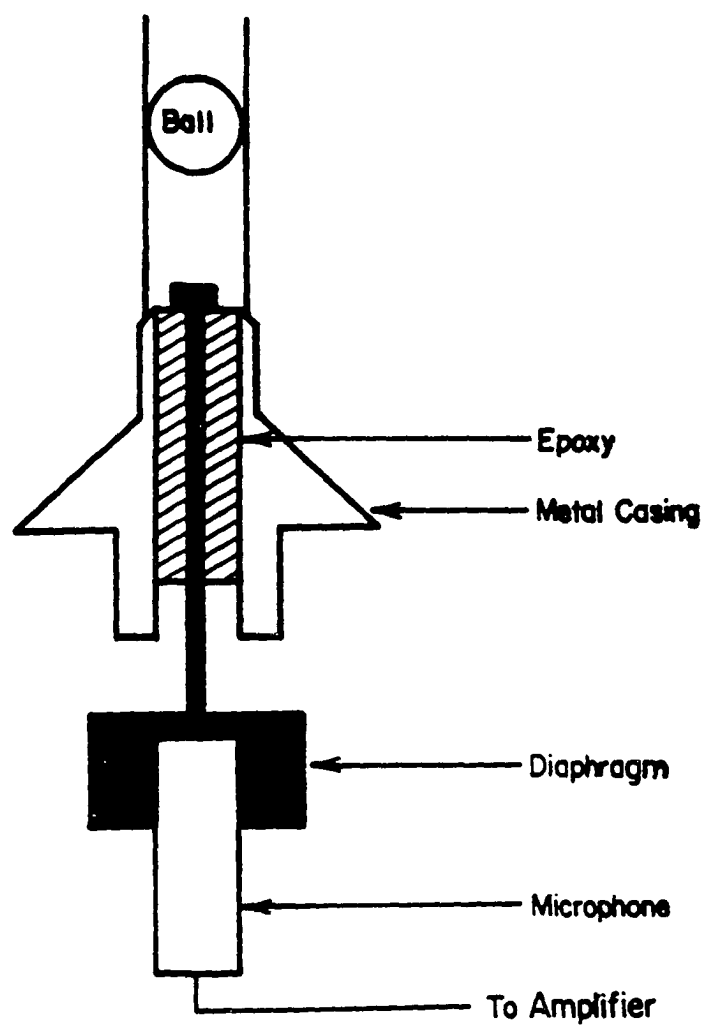


Figure 2-9: Schematic Diagram of Audio Ball Detection Unit.

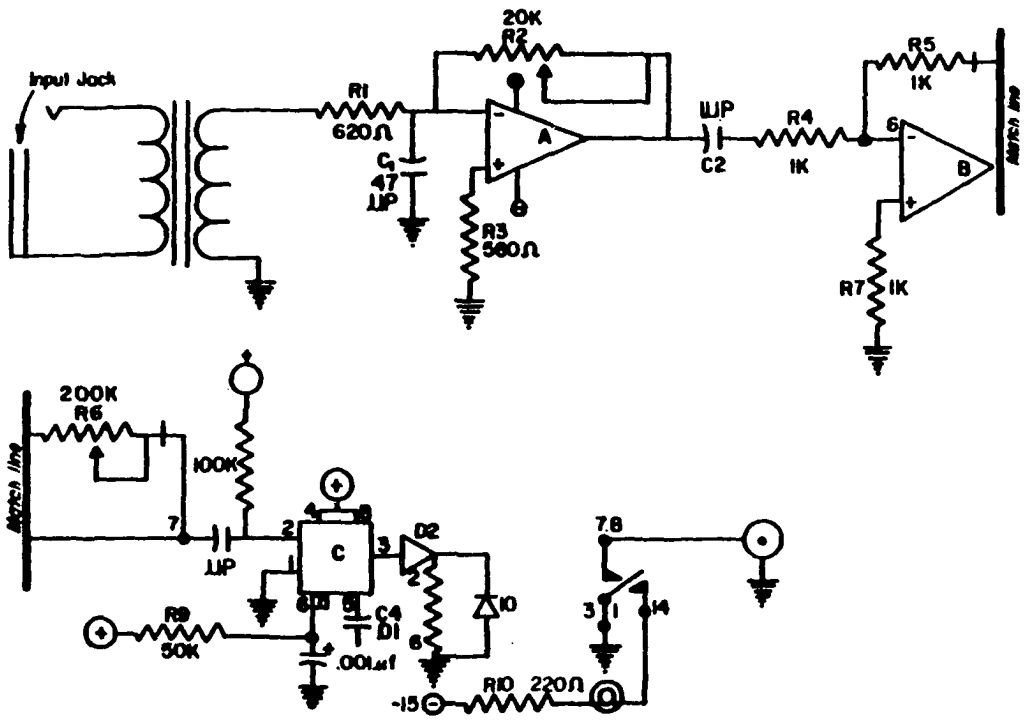


Figure 2-10: Schematic Diagram of Circuit for Audio Ball Detection Unit.

## CHAPTER 3

### 3.0 EXPERIMENTAL EQUIPMENT AND PROCEDURES

#### 3.1 Description of Experimental Equipment

A schematic diagram of the experimental apparatus is shown in Figure 3-1. The description of the equipment and measuring devices are given below.

##### 3.1.1 Viscometer -

The viscometer is a rolling ball type, manufactured by the Ruska Instrument Corporation (Serial number 1602-811-00). The maximum allowable pressure and temperature are 10,000 psia and 300 F respectively. The internal volume is approximately 61 cc.

This viscometer consists of three units: the viscosity test assembly, the auxiliary control unit, and the audio ball detection unit (see Figure 3-2). The auxiliary control unit contains a temperature indicator and controller and the electric timer. The audio detection unit contains the amplifiers and circuits necessary to detect the arrival of the ball at the bottom of the tube and stop the timing device. The audio unit is connected to a microphone mounted on the lower end of the viscometer body.

The viscometer is mounted in journal leaning on two "A" frames as shown in Figure 3-3. Three stops are mounted on the test assembly to provide roll angles of 23, 45, 70°. This entire assembly is mounted on a base plate which has leveling screws and a reference level vial.



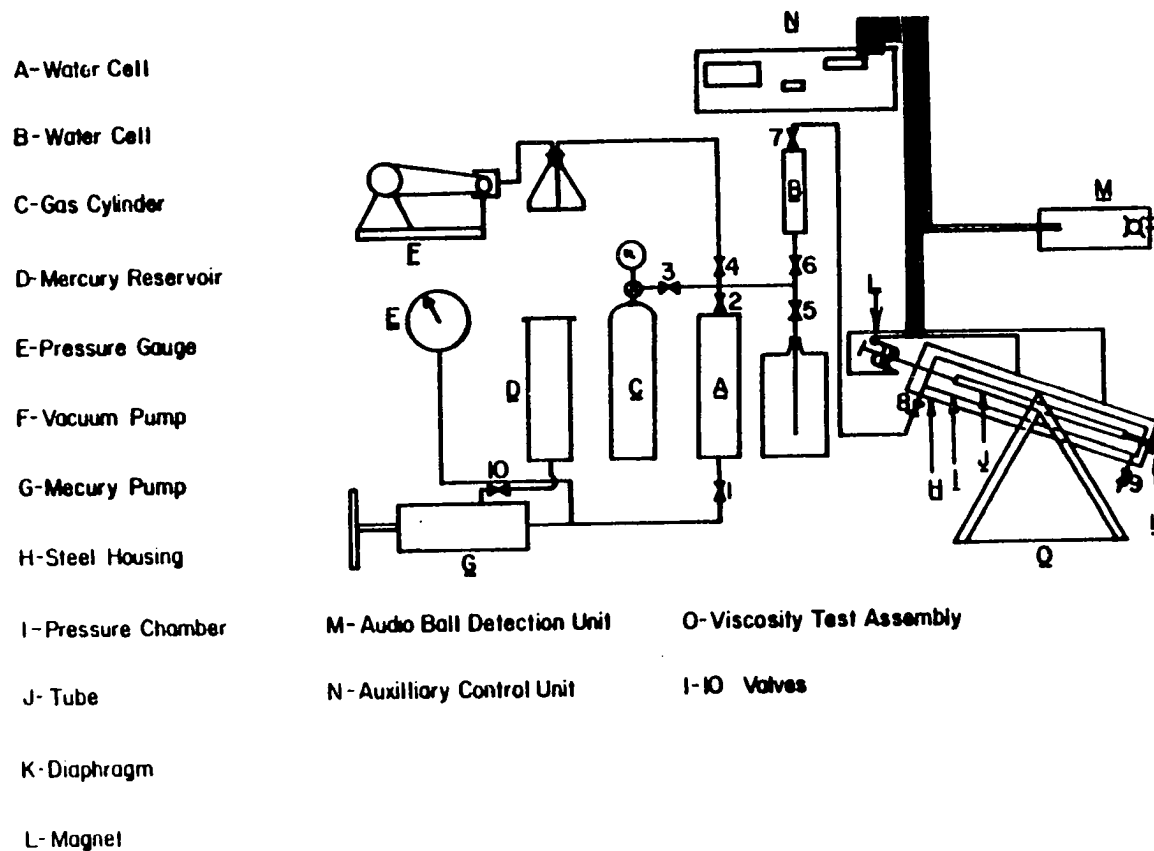


Figure 3-1: Schematic Diagram of the Experimental Apparatus.

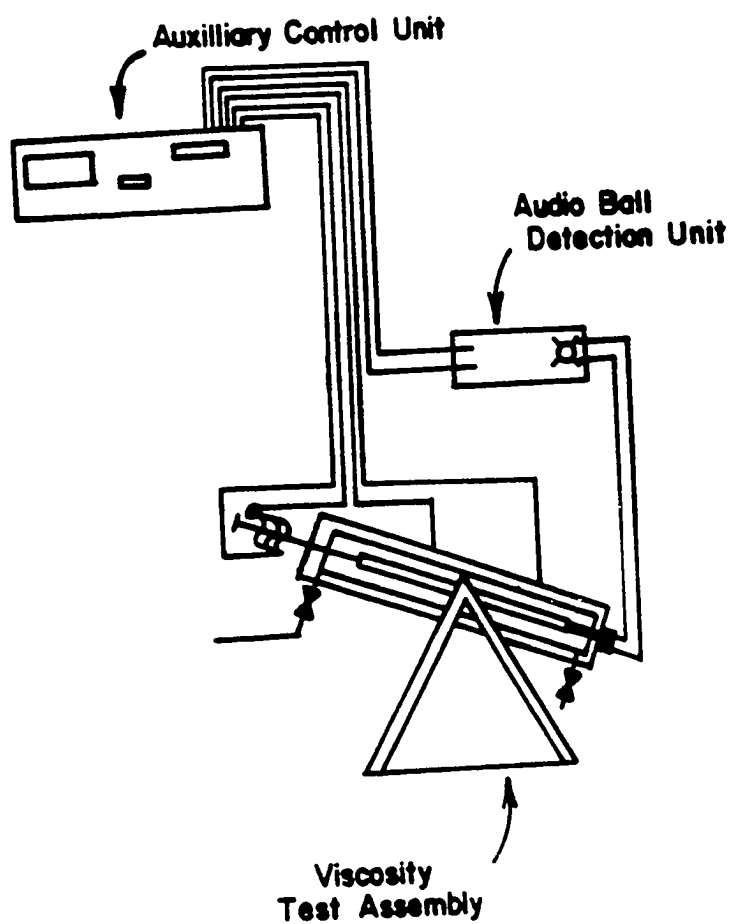
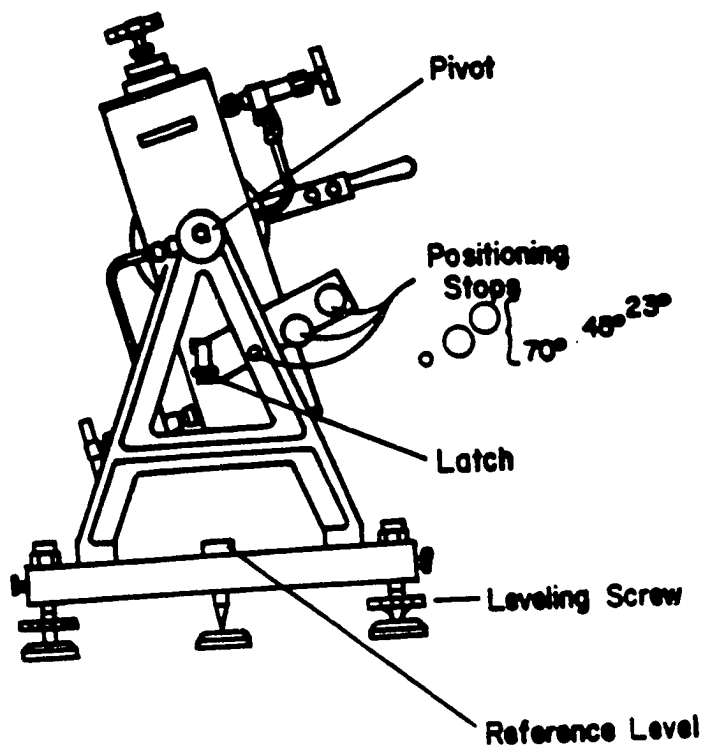


Figure 3-2: Schematic Diagram of the Viscometer Units.



**Figure 3-3: Schematic Diagram of the Viscometer.**

### 3.1.2 The Heating And Timing Unit

The viscometer temperature is controlled through an insulated electrical resistance heating jacket, (LFE Series 230) secured to the pressure housing. The heating elements are located along the length of the pressure housing to distribute the heat to the entire fluid column in the viscometer. A thermocouple and indicating proportioning controller maintain the temperature of the system constant. A digital counter is used for setting the temperature of the system.

The timing unit contains a digital clock with a precision of 0.01 second. The timing unit measures the time elapsed between the release of the ball and its arrival at the bottom of the viscometer tube.

### 3.1.3 The Mercury Pump

A mercury pump was used to pressurize the system and transfer fluids. The pump, manufactured by Ruska Instruments, is a hand operated single-cylinder, positive displacement piston pump (Serial number is 30890). A plunger of uniform diameter is used to displace the mercury. A linear scale is provided for measuring the position of the plunger. An additional dial indicator is provided on the pump spindle for

added resolution of piston position. The pump readings from the linear and dial scale correspond closely to cubic centimeters of mercury displaced. The precise relationship between "pump reading" and volume displaced is determined by calibration.

#### 3.1.4 The Pressure Gauge

Pressure was measured with a standard Heise gauge with a 403 stainless steel Bourdon tube. This gauge range is from 0 to 10,000 psig with intervals of 10 psig. The gauge is calibrated with a piston gauge by the manufacturer. The accuracy is .02% of the full scale. The gauge is manufactured by Dresser Industries.

#### 3.1.5 Fluid Injection Manifold

A schematic diagram of the fluid injection system is presented in Figure 3-1. All transfer lines were 1/8 inch stainless steel high pressure tubing. The valves were Ruska Instrument high pressure needle valves.

Water was injected into the viscometer from a 750 cc high pressure sample bottle by mercury displacement. Methane was injected directly from the supply cylinder through the manifold system. Since fine particles can interfere with operation of the equipment, a Ruska model 2076 filter was placed in the injection line.

### 3.2 MATERIALS

The fluids used in this research are pure distilled water, nanograde pentane, and methane.

Nanograde pentane purchased from Mallinckrodt was used as a calibration fluid.

Methane with a minimum purity of 99.97% was purchased from the Matheson Corporation. It was contained in a gas cylinder at a pressure of approximately 1500 psig.

### 3.3 EXPERIMENTAL PROCEDURE

#### 3.3.1 Sample Preparation

Viscosity measurements were made with methane saturated water at varying saturation pressures. This was accomplished by preparing a sample saturated at high pressure then lowering the pressure in discreet steps without removing any of the evolved gas.

Three samples of gas saturated water were prepared for this research. Samples one and two were at 8000 psia at 100 and 150°F. Sample three was prepared at 100°F and 1500 psia. The amount of gas required to saturate these samples was estimated from Figure 1-1. Using Figure 1-1, at the specified temperatures (100, 150°F) and pressures (1500, 8000 psia), the volume of gas required to saturate 61 cc of water (volume of viscometer) was found. This amount of gas was added to the water. The precise saturation pressure for all samples was determined experimentally by noting the change in compressibility at the bubble point. Figures 3-4, 3-5, and 3-6 show the saturation pressure for these samples. Table 3 contains the data for these Figures.



TABLE 3  
SATURATION PRESSURE

100 F		150 F		100 F	
Pressure psia	Mercury Withdrawal cc	Pressure psia	Mercury Withdrawal cc	Pressure psia	Mercury Withdrawal cc
8000	0.00	8000	0.00	1500	0.00
7950	0.110	7950	0.120	1400	0.210
7900	0.220	7900	0.240	1300	0.420
7850	0.330	7850	0.370	1200	0.620
7800	0.4440	7800	0.490	1100	0.9150
7750	0.560	7750	0.630	1000	1.1900
7700	0.6750	7700	0.770	900	1.4900
7650	0.80	7650	0.9050		
7600	0.9150				
7550	1.0500				
7500	1.1950				

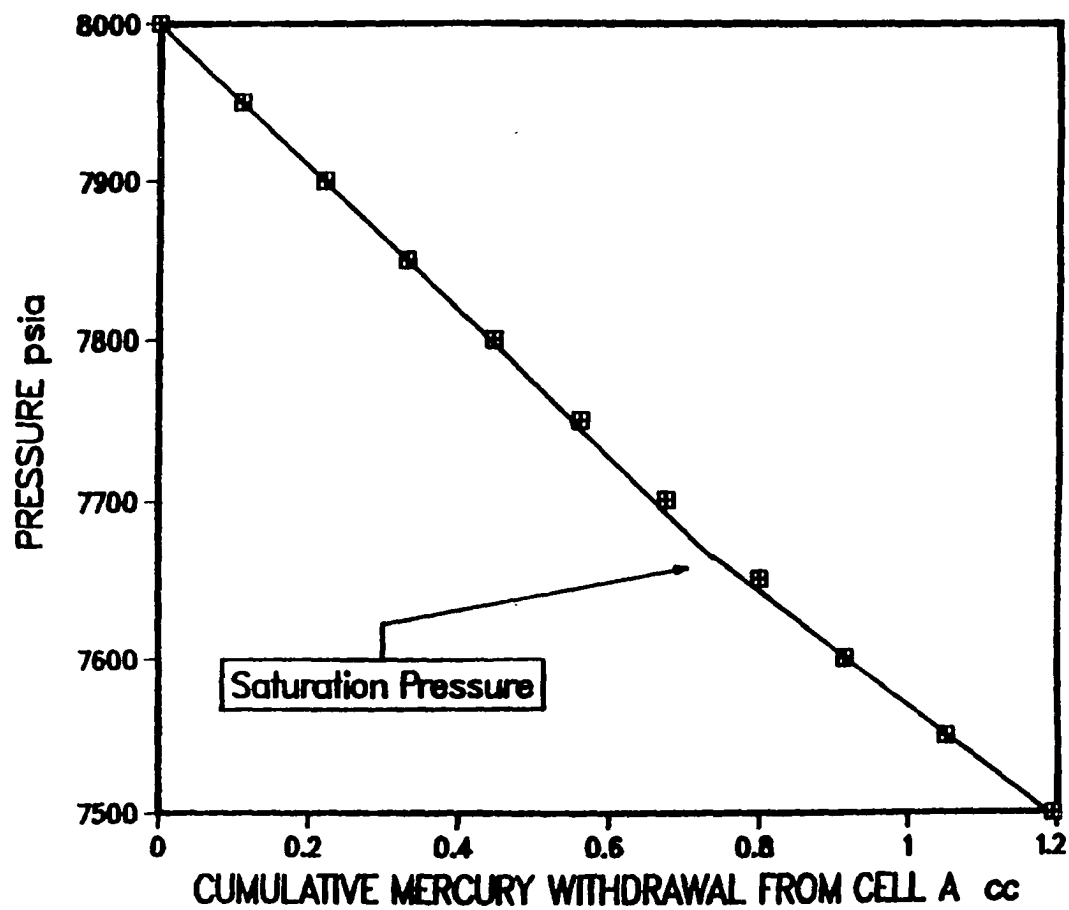


Figure 3-4: Saturation Pressure Curve for 100° F.

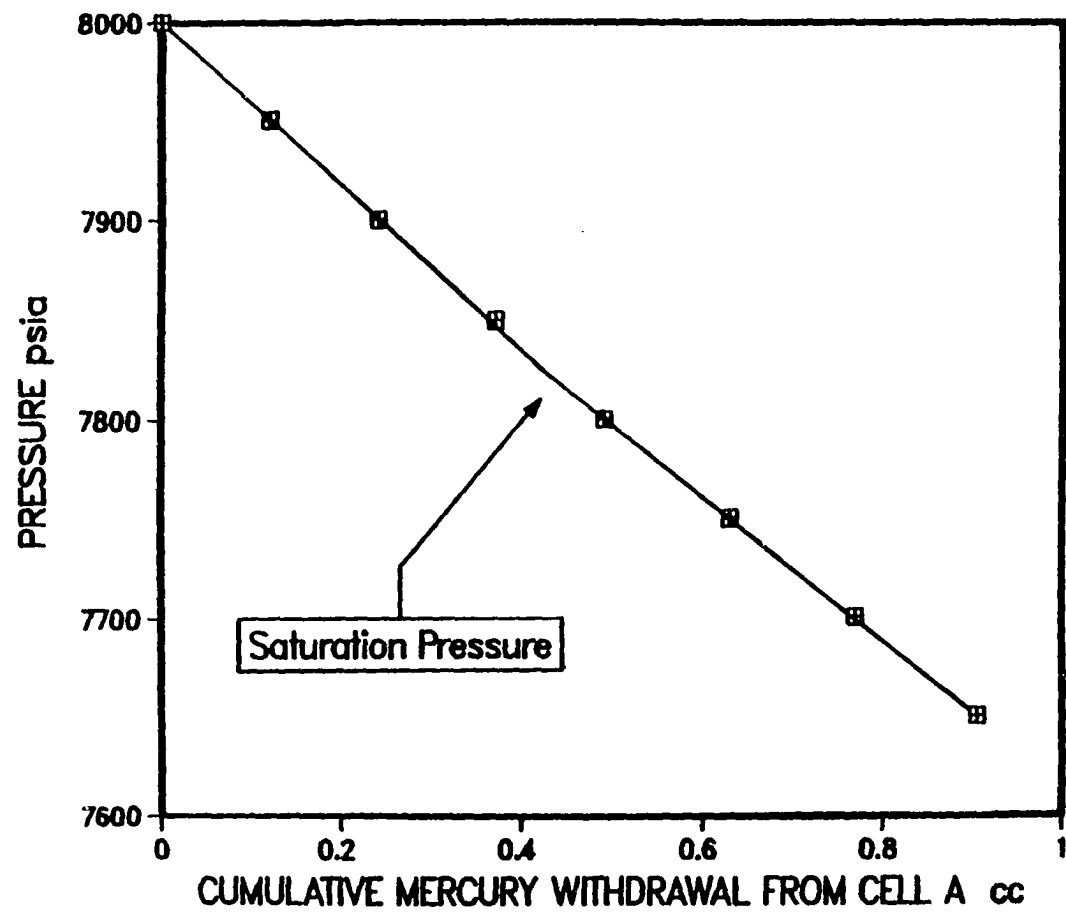


Figure 3-5: Saturation Pressure Curve for 150° F.

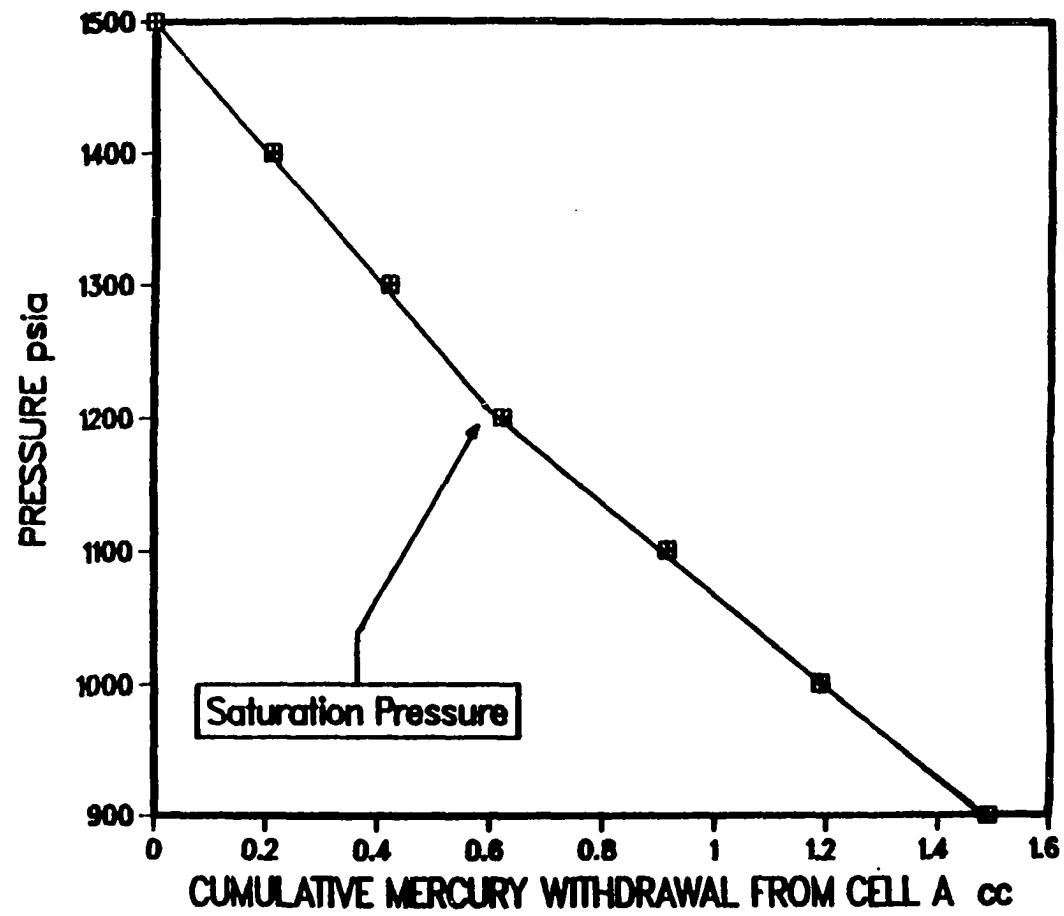


Figure 3-6: Saturation Pressure Curve for 100° F.

Since the pressures were dropped below the initial saturation pressures without removing the complete gas phase, the samples remained saturated at any pressure below the original bubble point pressure throughout the experiment.

The procedure used to prepare all of these samples was as follows:

All of the samples were prepared inside the viscometer. To do so, the apparatus was evacuated by starting the vacuum pump and closing the valves 1,3,5,9. All the remaining valves were left open (figure 3-1 shows the location of valves and cells). After evacuation, valve 4 was closed and valve 1 was opened and the pure water from cell A was transferred into the viscometer by injecting the mercury into cell A. After the viscometer was filled with water, valves 8 and 2 were closed and valve 4 was opened and the cell B and the lines were evacuated again. Valve 4 was then closed and valve 3 was opened and gas was injected into cell B until the pressure inside of cell B and gas cylinder was the same (1500 psia). Since the volume of cell B was fixed (20 cc), then the amount of gas required to saturate 61 cc (volume of water in the viscometer) of water was determined by

pressure adjustment. Valve 3 was closed and valve 1 and 2 were opened. Then valve 4 was slowly opened and gas was removed from cell B until the desired pressure was reached. Then valve 4 was shut and water was injected into cell B to pressurize the methane to a specified pressure. Then valve 8 was opened and the pressure was adjusted to the specified pressure by injecting more mercury into cell A. Valve 1 was then opened slowly and mercury was injected into cell A to maintain the pressure displacing water from cell A to cell B, thus displacing gas from cell B into the viscometer, and simultaneously displacing water from the viscometer. The volume of gas displaced was less than 10 cc in all cases. To assure that all of the gas was injected, about 20 cc of fluid was injected. After 20 cc of water was displaced from the viscometer, valves 9 and 8 were closed in order to isolate the sample in the viscometer from the rest of the apparatus. To make sure that no gas remained in the lines or in cell B, the pressure inside the lines and cells was dropped gradually to atmospheric pressure. If the compressibility of the system remained high, it was assumed that no gas remained.

At this point, the viscometer was turned on, the temperature adjusted to the desired temperature, and the sample was rocked to achieve equilibrium. The rocking took place for 15 minutes every 3 hours for 12 days. After that, the roll time was measured using the procedure described in the next section. After the first reading, the pressure was dropped to a new pressure by withdrawing mercury from cell A and, thus, water from the viscometer. The sample was rocked for 15 minutes every three hours for a period of 24 hours. This procedure was repeated for each new pressure throughout the range of pressure.

### 3.3.2 Operating Procedure Of The Viscometer

#### 3.3.2.1 Ball Diameter Selection -

A correct diameter ratio between the ball and the tube had to be selected using Figure 2-2. Since the tube diameter was fixed, the only choice was to change the ball diameter to change the ratio.\*

### 3.3.2.2 Cleaning

Any solid particles in the fluid will interfere with the free roll of the ball. Thus the test assembly must be thoroughly cleaned. This was accomplished with a light oil and thin paper. To make sure that a film of cleaning liquid was not left behind, the apparatus was flushed with acetone and the sample liquid.

### 3.3.2.3 Sample Charging

At this point, the ball was placed into the viscometer and the top and bottom cap of the test assembly was closed. Then the entire apparatus was evacuated. This was done by closing the valves 1,3,5,9 (keeping the rest of the valves open) and turning on the vacuum pump.

After evacuating the apparatus, valve 4 was closed and the sample fluid was charged into the viscometer. This was done by opening valve 1 and injecting mercury from the pump into cell A to displace the sample from cell A into the viscometer. After the sample was placed in the viscometer, the power switch was turned on and the temperature and pressure were set.



The sample was then allowed to sit for at least four hours to reach thermal equilibrium. The sample was then brought back to the desired pressure and allowed to sit for at least one hour. Next, the apparatus was inverted to bring the ball to the upper end of the measuring barrel. The ball was held in position by turning on the electromagnet.

The instrument was then returned to the operating position and the clock reset. The ball remained at the top of the measuring barrel until the switch was changed to the "drop" position, turning off the electromagnet and starting the clock. The electromagnet should not be left on any more than is absolutely necessary as the instrument will tend to become permanently magnetized.

As soon as the ball made contact with the bottom of the tube, the microphone attached to the diaphragm picked up the sound and stopped the clock. The time which appears on the timer was then recorded as the "roll time".

### 3.3.3 Calibration Procedure

To calibrate the viscometer, different fluids of known density and viscosity were used. For this study, pure water and pentane were used. The ball diameter which was used for the entire experiment was 0.252 inches (a separate calibration is necessary for each ball diameter).

The viscometer was calibrated at 100°F and 150°F at pressures up to 8,000 psia. The instrument was calibrated for angles of 23°, 45°, and 70°.

To establish the equation relating the viscosity of the fluid to roll time and density, the following procedure was used:

At each angle the roll time was measured four times. The average roll time for each angle was then determined. The average roll time was then multiplied by the difference between the ball density and the fluid density. The results of the calibration can be seen in Tables 4, 5, 6, and 7 in Appendix A. Viscosity of the calibration fluid in centipoise was plotted versus the product of roll time and density difference. The calibration plots are presented in Figures 3-7, 3-8, and 3-9.

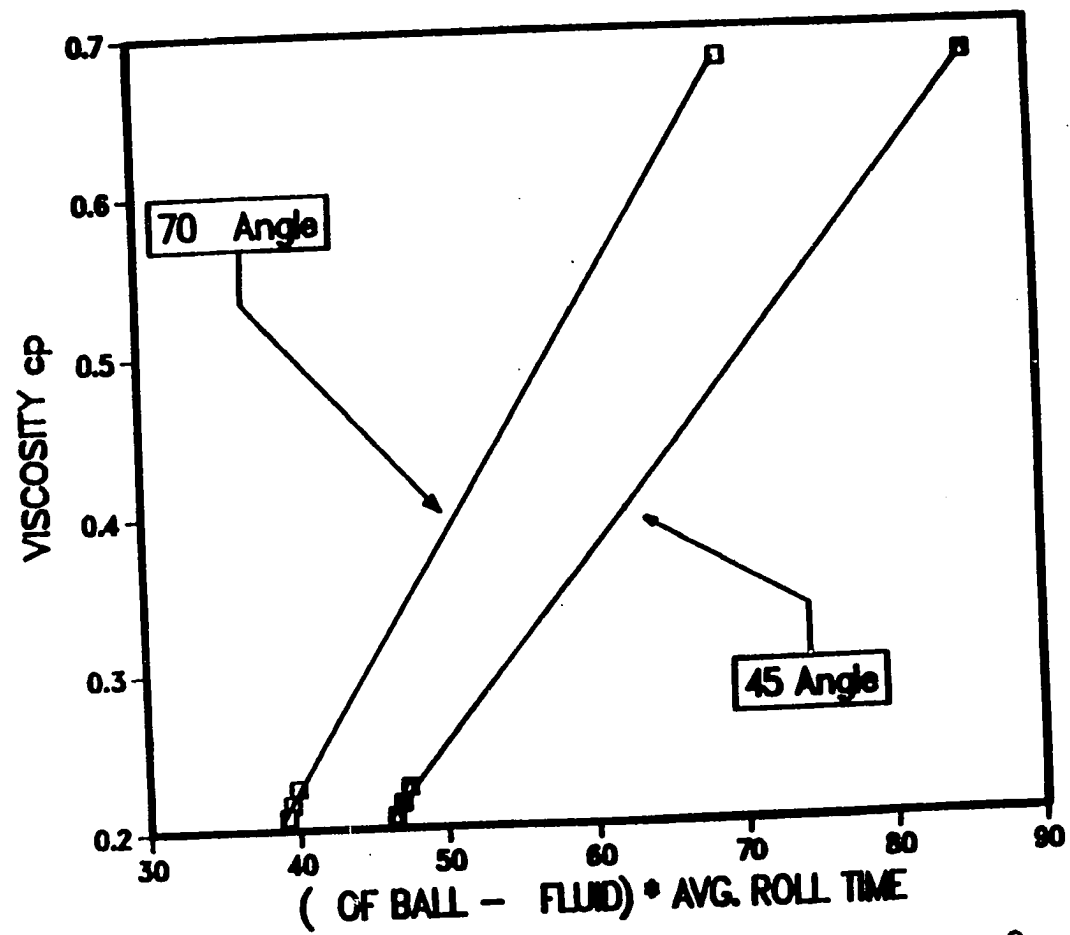


Figure 3-7: Calibration Curve for 45 and 70° Angles at 100°F.

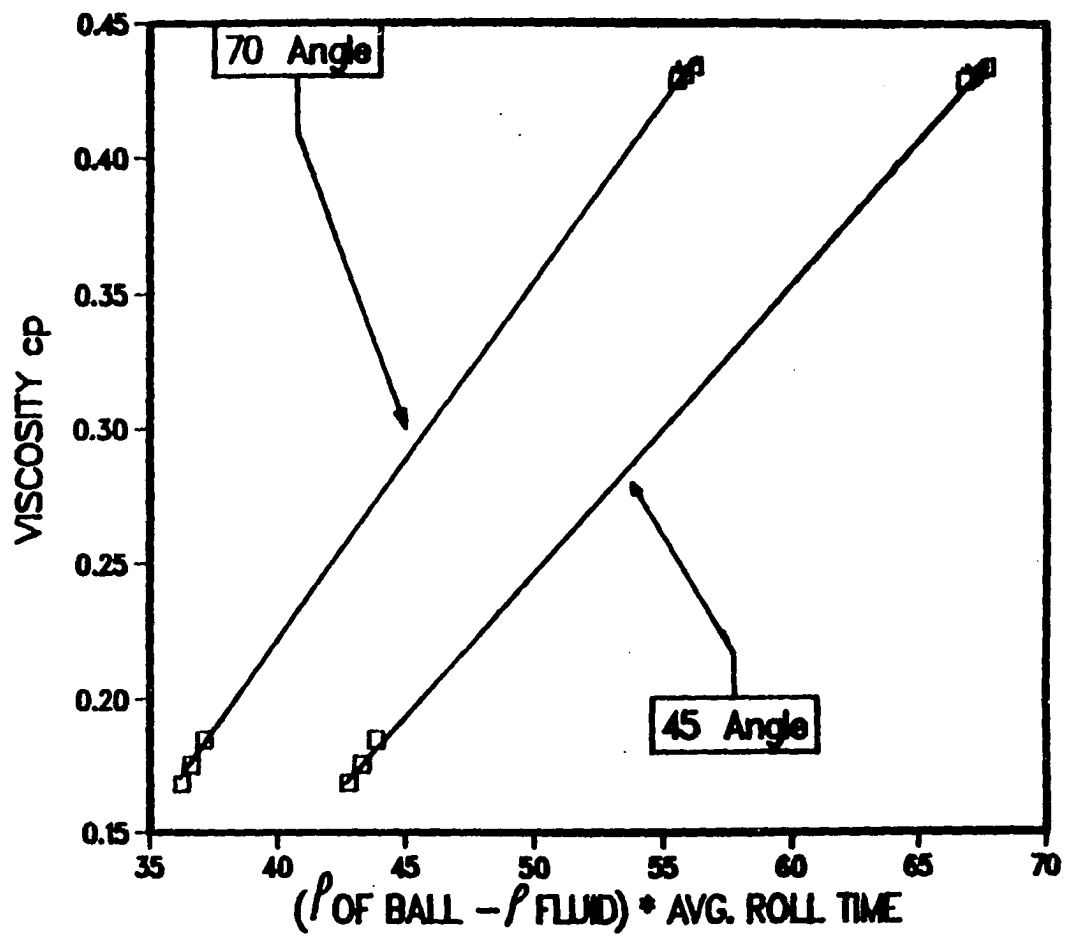


Figure 3-8: Calibration Curve for 45 and 70° Angles at 150° F.

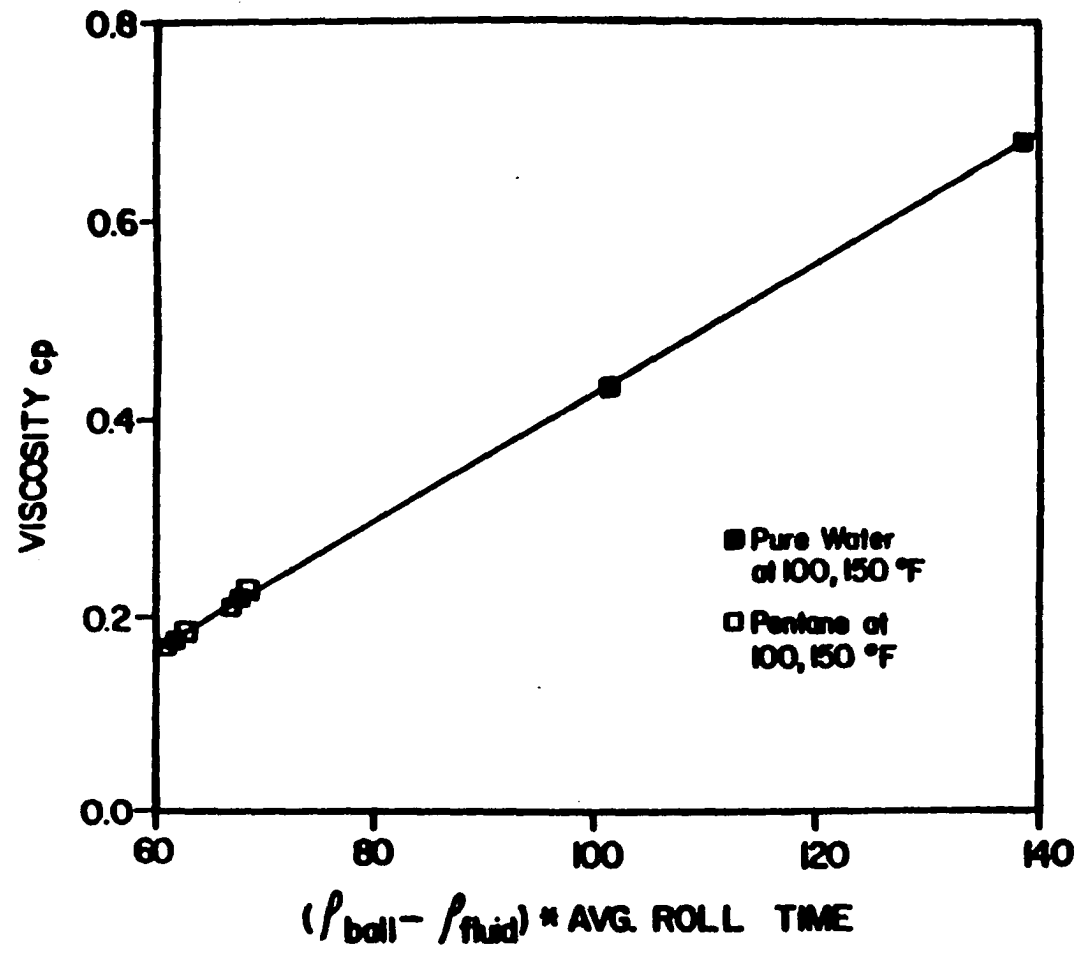


Figure 3-9: Calibration Curve For 23° angle.

The equations for these lines were established by least squares fit. Equations 3-1 through 3-4 are for temperatures of 100 and 150°F and inclination angles of 70° and 45° respectively. Equation 3-5 is the calibration equation for 23° at temperatures of 100 and 150°F. These equations are as follows:

$$\mu = 0.01525 (\tau(\rho_{\text{ball}} - \rho_{\text{fluid}}) - 24.6) \quad \text{..... (3-1)}$$

$$\mu = 0.01189 (\tau(\rho_{\text{ball}} - \rho_{\text{fluid}}) - 28.3) \quad \text{..... (3-2)}$$

$$\mu = 0.01339 (\tau(\rho_{\text{ball}} - \rho_{\text{fluid}}) - 23.5) \quad \text{..... (3-3)}$$

$$\mu = 0.01078 (\tau(\rho_{\text{ball}} - \rho_{\text{fluid}}) - 27.0) \quad \text{..... (3-4)}$$

$$\mu = 0.0065717 \tau(\rho_{\text{ball}} - \rho_{\text{fluid}}) - 0.23128 \quad \text{..... (3-5)}$$

It should be noted that the calibration equations do not indicate a zero intercept as implied in Equation 2-1. Ideally, several fluids of differing viscosity could be used to better define the "curve". However, the generally accepted procedure is to merely linearize the data over the range of interest. It is assumed, however, that the curves were still applicable in the region of interest.

Equation 3-5 was used to determine the viscosity of the sample fluids throughout the project.

The operating range of the rolling ball viscometer depends on the critical Reynolds Number ( $Re$ ) for the apparatus. The operating  $Re$  must be less than the critical  $Re$  to have a laminar flow. As reported by Hubbard and Brown (21), this critical  $Re$  depends on the ratio of the ball diameter to the tube diameter. With the 0.252 inches ball diameter used for the study, the diameter ratio is 0.973, yielding a critical  $Re$  of 20.0

As the inclination angle of the assembly increased, the terminal velocity of the ball increases also. This increase in the terminal velocity of the ball leaves us with a higher  $Re$ . To have the  $Re$  as low as possible, the inclination angle of  $23^\circ$  as opposed to  $45^\circ$  and  $70^\circ$  was chosen for this experiment.

#### 3.3.4 Viscosity Measurement

The  $23^\circ$  inclination angle was used for measuring the viscosity of the methane saturated water. To determine the viscosity of the fluid, the experiment was run four times for each pressure and temperature

and the roll times were recorded. The average roll time was then calculated and the viscosity of the fluid was determined using Equation 3-5. The data for these calculations can be seen in Tables 8 through 10 in Appendix B. It should be noted that with the audio detection system, loud noises and significant vibration in the building will cause erroneous readings from time to time. Generally speaking, these readings are obvious, and have been omitted from the data.



## CHAPTER 4

### DATA COLLECTION

#### 4.1 Viscometer Calibration

The viscometer was calibrated using Equation 2-1. The constant in Equation 2-1 was determined by plotting the viscosity of calibrated fluids versus the product of roll time and density difference on linear graph paper (see calibration procedure in Chapter 3 for details). The equation of the line was then established with a least squares fit.

Distilled water and pentane were used as the calibration fluids. The viscosity of these fluids was obtained from Hubbard and Brown (22) and the Steam Tables (5). The density of pentane was obtained from Starling(23). The density of water was computed using empirical formulas given by Rowe and Chou (24). A formula provided by Ruska Instruments was used to determine the density of the stainless steel ball. The equations used are reproduced below:

$$\rho_{\text{water}} = (A(T) - P_1 \cdot B(T) - P_1^2 \cdot C(T))^{-1} \quad \text{..... (4-1)}$$

where

$$A(T) = 5.916365 - 0.01035794T + 0.9270048 \times 10^{-5}T$$

$$- \frac{1127.5221}{T} + \frac{100674.1}{T^2}$$

$$B(T) = 0.5204914 \times 10^{-2} - 104821 \times 10^4 T$$

$$+ 0.8328532 \times 10^{-8} T^2 - \frac{1.1702939}{T}$$

$$+ \frac{102.2783}{T^2}$$

$$C(T) = 0.118547 \times 10^{-7} - 0.6599143 \times 10^{-10}T$$

$$\rho_{ball} = 7.754 - (0.000048 \times T)$$

..... (4-2)

The viscosities, densities, and roll times determined are given in Tables 4 through 7 in Appendix A. The calibration curves are plotted in Figures 3-7 through 3-9. The appropriate calibration Equations are listed as Equations 3-1 through 3-5.

#### 4.2 Viscosity Calculation

The viscosities of the methane saturated samples were calculated from Equation 3-5 at measured roll

times over the temperature range of 100 to 150°F at saturation pressures ranging from 0 to 7000 psia.

$$\mu = 0.0065717 \tau(\rho_{\text{ball}} - \rho_{\text{fluid}}) - 0.23128$$

..... (3-5)

To calculate the viscosity of any liquid, the average roll time, density of the S. S. ball, and the density of the liquid must be known. The average roll time of the ball for each sample was determined as described in Chapter 3. The density of the ball was calculated using Equation 4-2. The density of the methane saturated water is related to the density of distilled water at base conditions by the following equation ( Amyx et al. (13) ):

$$\rho_{\text{fluid}} = 1.601846 \times 10^{-2} \frac{62.34 + \frac{R_{\text{sw}} \text{ X MW}}{379 \text{ X } 5.615}}{B_{\text{w}}}$$

..... (4-3)

As seen from Equation 4-3. the density of water at base conditions, solubility of methane in water, and the formation volume factor of the gas saturated

water at temperatures and pressures of interest must be known to calculate the density of gas saturated water at these conditions.

Figure 1-1 was used to obtain the solubility of methane in water. The density of the water at base conditions ( $T=60^{\circ}\text{F}$ ,  $P=14.7$  psia) used was  $62.34 \text{ lb/ft}^3$ . The data on the formation volume factor of gas saturated water was obtained from Dodson and Standing (14). Using these values, the viscosities of the samples were calculated from Equation 3-5. These results are presented in Tables 8 through 10 in Appendix B.

In this study, the Reynolds Number ( $\rho v d / \mu$ ) must not exceed the critical value of 20.0. For a viscometer tube length of 8 inches and equivalent diameter (difference between tube diameter and ball diameter) of 0.007 inches, the maximum Reynolds Number observed was 14.6 (for pentane at  $150^{\circ}\text{F}$  and 100 psia), which is less than the critical value of 20.

Several "runs" were made for each measurement. The average roll time was then used along with the fluid and ball densities in Equation 3-5 to calculate the fluid viscosity. The highest standard deviation among roll times observed was 0.049 for an average

roll time of 14.86. All physical property data used had an error of less than 1% as reported by the respective investigators.

## CHAPTER 5

### RESULTS

The intent of this research was to measure the viscosity of methane saturated water. To accomplish this, modification of the standard rolling ball viscometer allows its use with electrolyte solutions was necessary.

The viscometer was modified using an inexpensive method which allowed its use for measuring the viscosity of electrolyte solution. This modification is described in Chapter 2. In general, it was found to be inexpensive and easy to operate.

Figure 5-1 shows the viscosity of methane saturated water at various methane saturation pressures at a temperature of 100°F determined in this study. Data are presented in Table 8 in Appendix B. The viscosity of pure water for the same condition is also shown on this figure. As can be seen, the viscosity of methane saturated water increased with an increase in saturation pressure. The increase in viscosity occurred until a saturation pressure of 2500 psia was reached. From 2500 psia to 5500 psia the viscosity remained almost constant. After 5500 psia, viscosity started to increase again. The viscosity of

the gas saturated fluid showed an increase of about 8% at 7000 psia, as compared to the viscosity of pure water at the same condition.

Figure 5-2 shows the viscosity of methane saturated water at its saturation pressure for a temperature of 150°F for pressures from 14.7 to 7000 psia. Data are presented in table 9 in Appendix B. The lower curve in the Figure 5-2 represents the viscosity of pure water.

The results for 150°F also showed an increase in the viscosity of methane saturated water compared to pure water viscosity. This increase is roughly 6.5% at 7000 psia. Most of the increase in viscosity was observed by a saturation pressure of 2000 psia. Unlike data taken at 100°F (Figure 5-1), no plateau was observed.

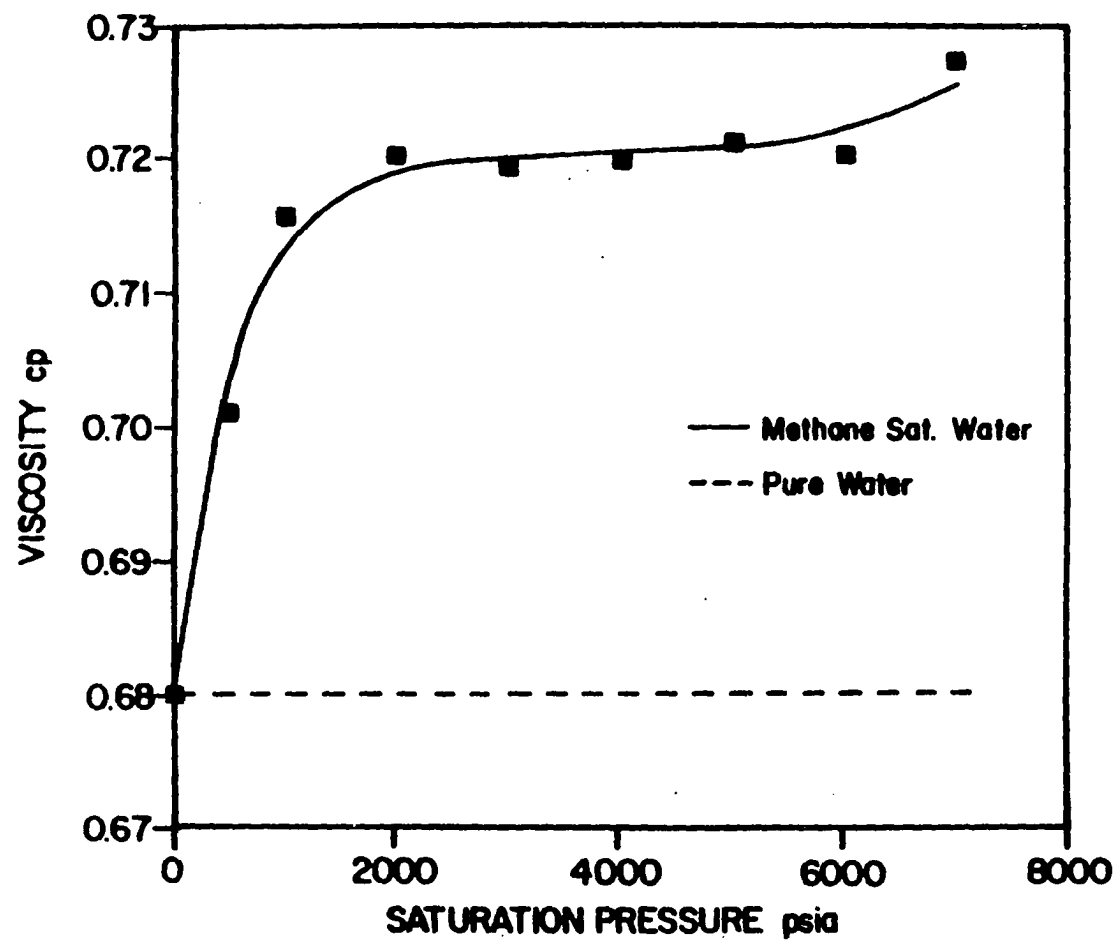


Figure 5-1: Viscosity of Methane Saturated Water at 100 °F.



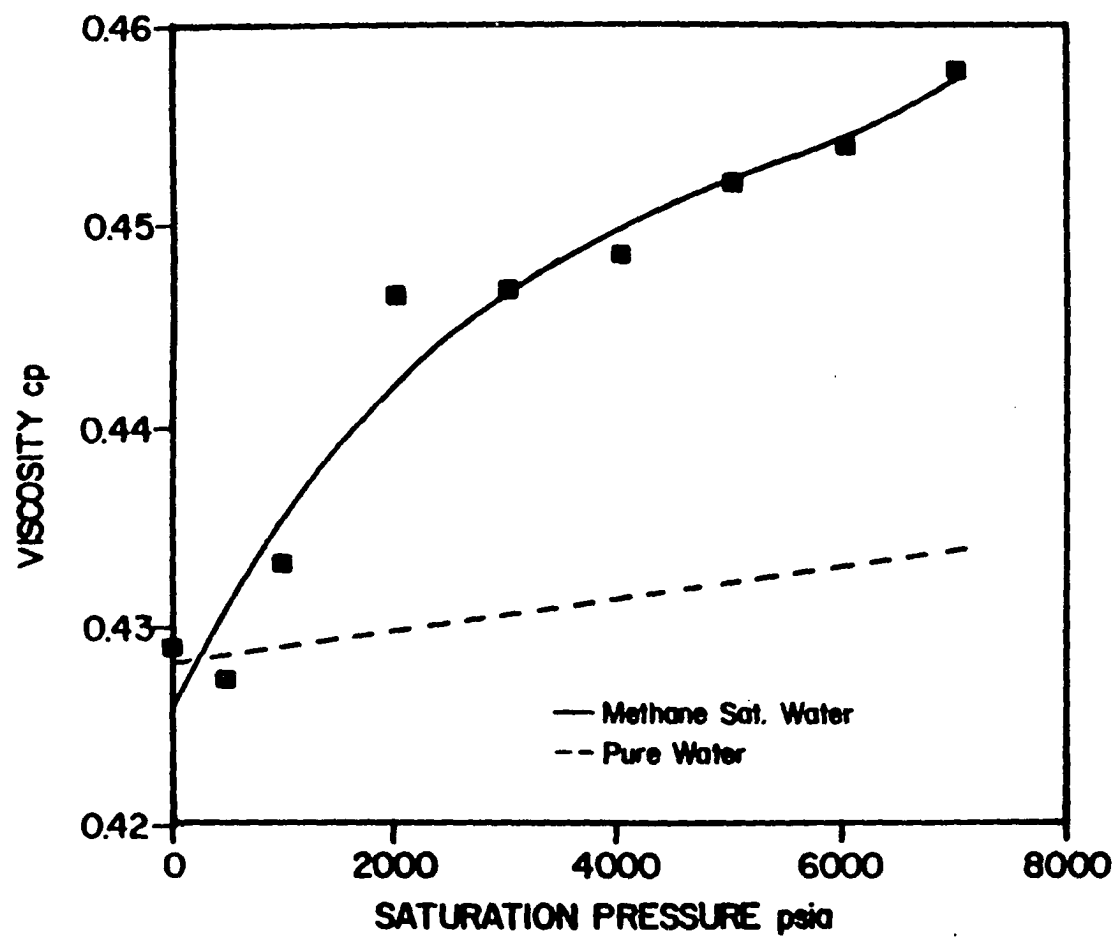


Figure 5-2: Viscosity of Methane Saturated Water at 150 °F.

The curve in Figure 5-3 shows the viscosity of undersaturated samples as a function of pressure. Data are presented in Table 10 in Appendix B. The saturation pressure of the system is 1000 psia and temperature of 100<sup>o</sup>F. This figure also shows that the viscosity of fluid is increasing up to a pressure of 1000 psia (the saturation pressure), after that the viscosity of the samples remains unchanged though the pressure increases from 1000 psia to 7000 psia.

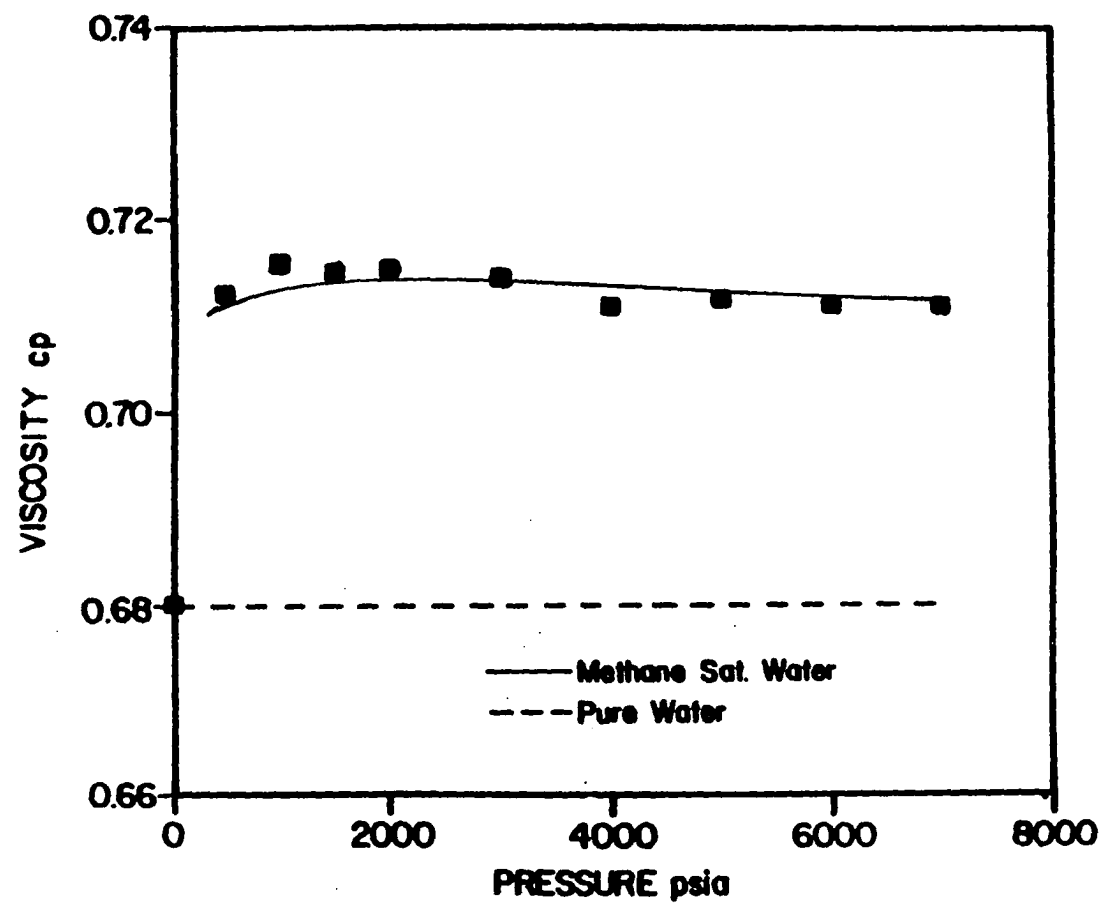


Figure 5-3: Viscosity of Undersaturated Methane Water.

Reid (25) reported that the viscosity of a liquid solution at reduced temperatures below .75 is highly dependent on the composition and structure of the liquid. This phenomena is more important if one of the liquids is polar or if a loose association exists between the molecules. McAllister (26) proposed an energy storage theory to explain the increase in the viscosity of a solution. He stated that interaction between layers in the velocity gradient are due to an activated jump of molecules between different layers. This kind of movement can be described in terms of a chemical reaction taking place in the solution. These molecules need to exceed the Gibbs free energy barrier in the process of movement. Further more, he insists that the movement of these molecules from one layer to other is dependent on the enthalpies and entropies of the solution.

According to this theory, the increase in the viscosity of gas saturated water might be interpreted as follows. For pure water, when a molecule such as A moves from one layer to another, it moves over an energy barrier. As a result, it interacts with another water molecule. Since all surrounding molecules are water molecules the interaction is A-A-A type. For the gas saturated water (binary) there

exist two types of molecules such as A and B. As McAllister (26) reports, when molecule A moves over the energy barrier it may interact with the same molecule, with B molecule, or with combination of A and B. As a result, the interactions could be A-A-A, B-B-B, A-B-A, B-A-B, A-A-B, A-B-B which is different than pure water. This change in the interaction between the molecules results in a change in the viscosity of solution. However as Reid (25) reports that no explanation as to why the viscosity of a solution goes to maximum or minimum has been published. This explanation is also just a hypothesis.

In the petroleum industry, gas in solution is normally referred to by gas solubility as compared to saturation pressure. Accordingly, Figures 5-4 and 5-5 show the viscosity of methane saturated water as a function of dissolved gas in solution at 100°F and 150°F respectively. The viscosity of the fluid increases as more gas goes into solution. The range of gas in solution for these two curves were from 0 to 31 SCF per STB of water. These two curves provide a convenient way to find the viscosity of methane saturated water as a function of dissolved methane in solution. However the data which were used to

construct these two curves are the same as the data used in Figures 5-1 and 5-2.

A more useful representation of the data could be obtained by plotting the viscosity ratio versus the saturation pressure. Figure 5-6 shows the ratio of viscosity of methane saturated water to the pure water for a pressure range of 14.7 to 7000 psia and temperatures of 100 and 150°F. The relative increase in the viscosity was less at higher temperature. This is largely because at 150°F the solubility of methane in water was less at 150°F than the solubility of methane in water at 100°F.

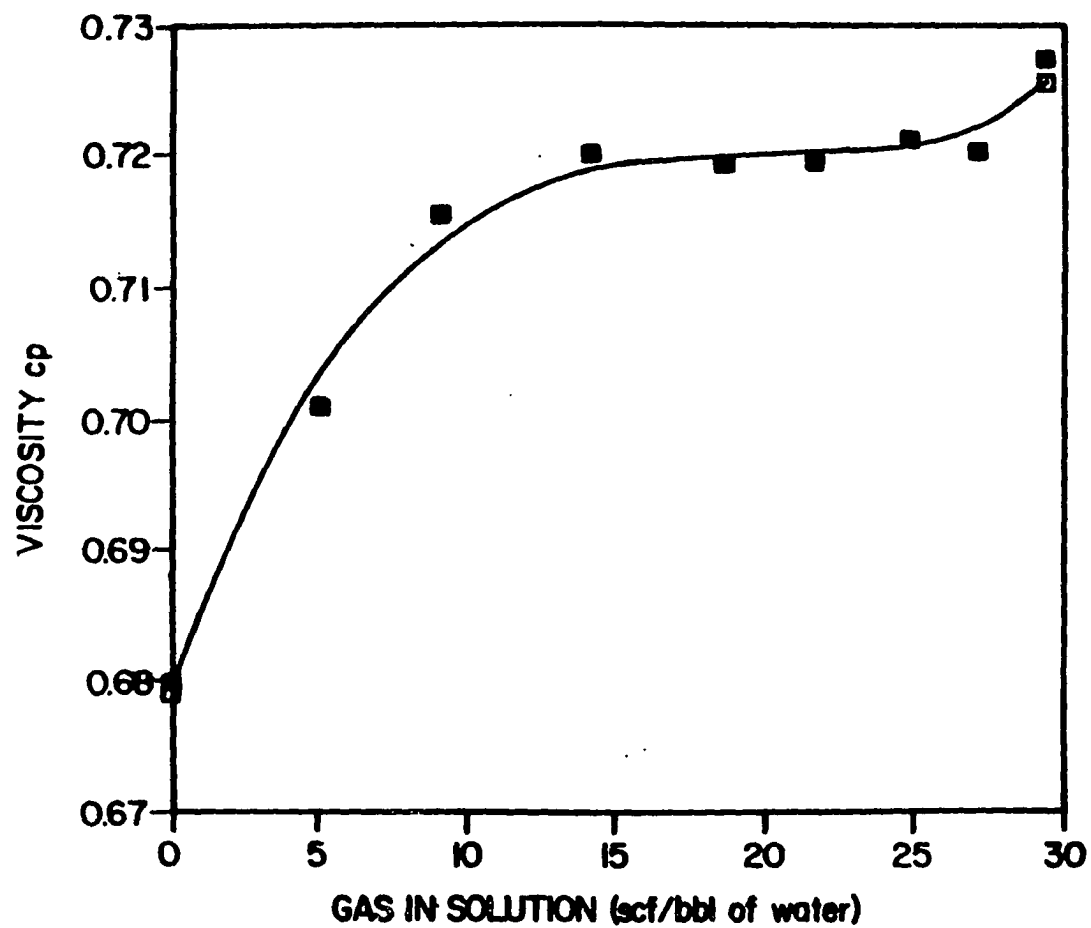


Figure 5-4: Viscosity of Methane Saturated Water at 100°F.

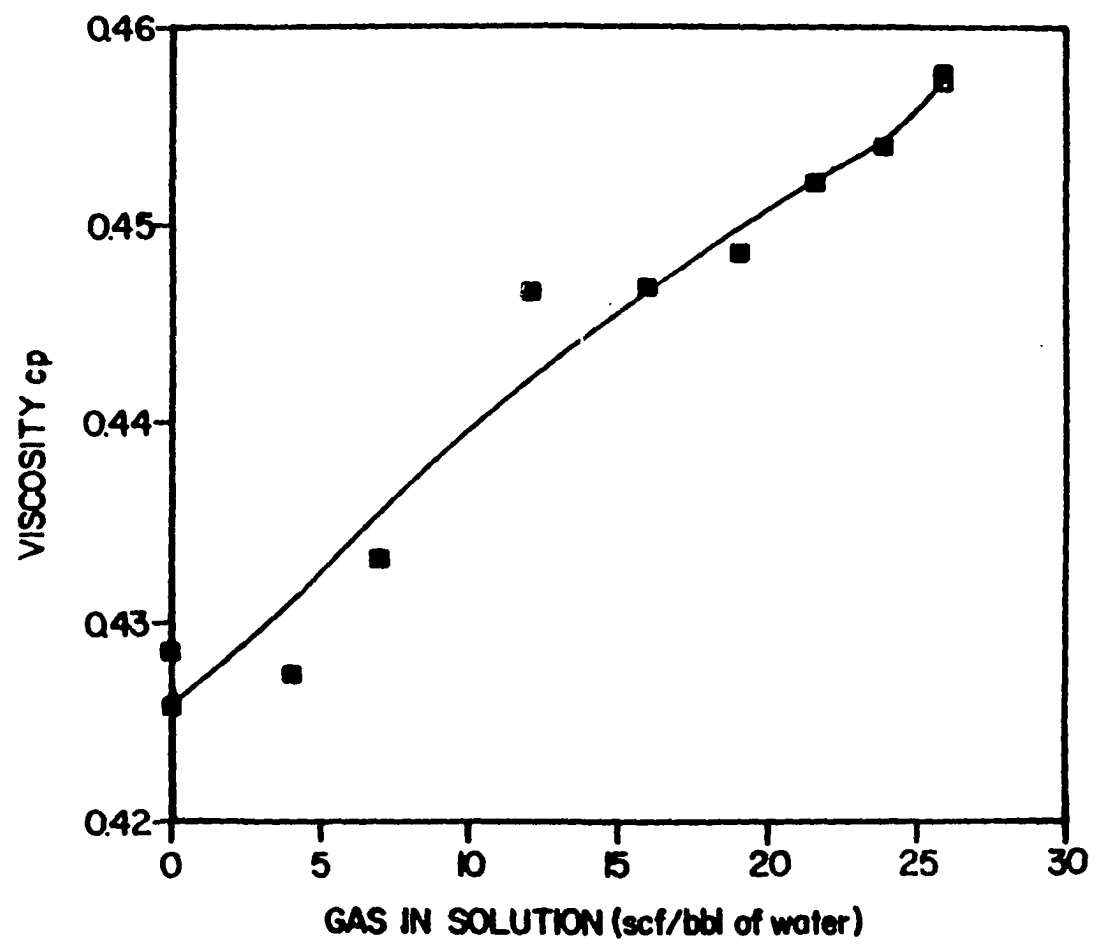


Figure 5-5: Viscosity of Methane Saturated Water at 150°F.



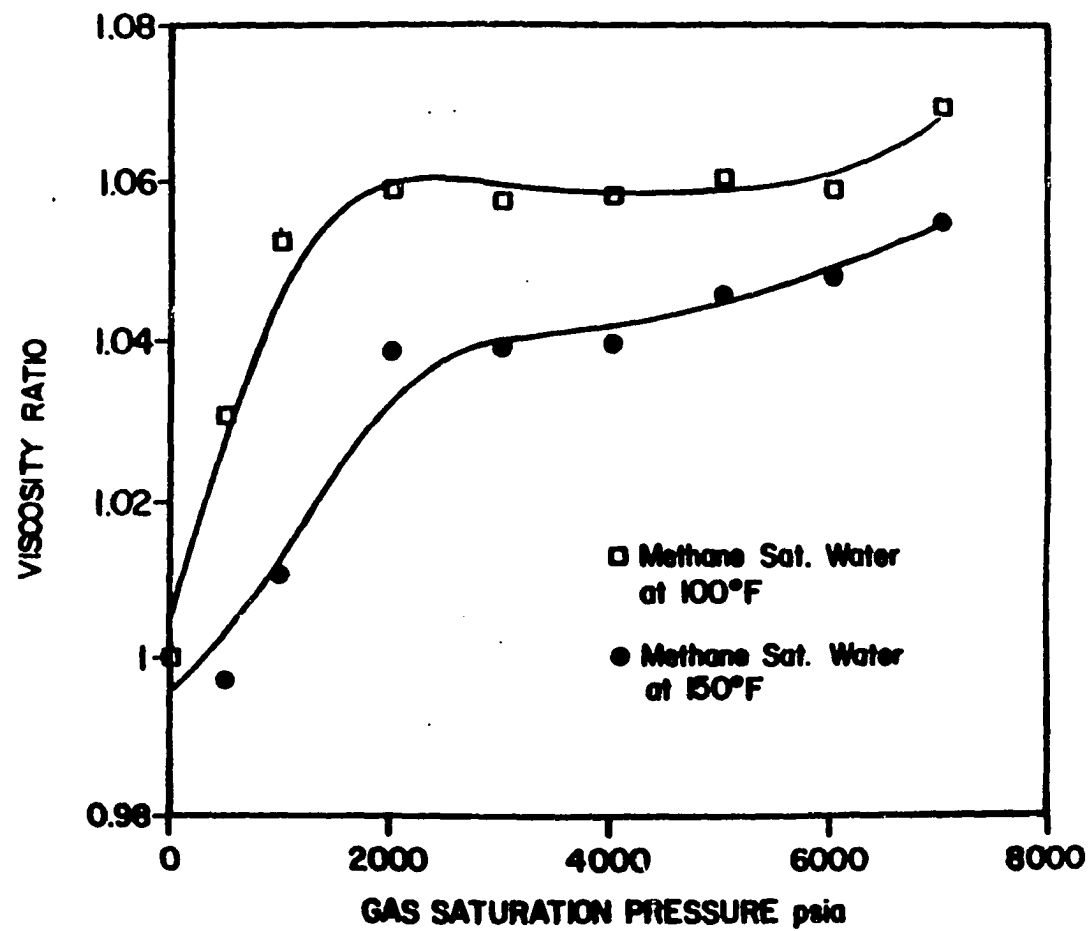


Figure 5-6: Viscosity Ratio ( $\mu$  sat. water/ $\mu$  pure water).

An empirical correlation was developed by using the data in Figures 5-1 and 5-2 .

$$\mu_p = \frac{T - 100}{50} \mu_{p(150)} + \left(1 - \frac{T - 100}{50}\right) \mu_{p(100)} \quad \dots\dots\dots (5-1)$$

where,

$$\mu_{p(100)} = a_1 \cdot a_2 p_s + a_3 \cdot a_4 p_s + a_5$$

$$\mu_{p(150)} = b_1 \cdot b_2 p_s + b_3 \cdot b_4 p_s + b_5$$

$$a_1 = -0.40380$$

$$a_2 = -0.00171$$

$$a_3 = 0.000011$$

$$a_4 = 0.000893$$

$$a_5 = 0.719955$$

$$b_1 = -0.030778$$

$$b_2 = -0.000376$$

$$b_3 = 0.000001$$

$$b_4 = 0.001129$$

$$b_5 = 0.456572$$

This correlation is not valid at temperatures below 100°F or above 150°F and pressures outside the ranges of 14.7 to 8000 psia. Note that the saturation pressure is in psia and temperature is in °F.

## CHAPTER 6

### CONCLUSION

In this study, the rolling ball viscometer originally built to measure the viscosity of a non-electrolyte liquid was modified to measure the viscosity of a electrolyte liquid. The modification was done in an inexpensive manner, thus enabling the viscometer to be used for measuring the viscosity of methane saturated water (electrolyte solution).

For this work, the modified rolling ball viscometer was used to measure the viscosity of methane saturated water. The data were taken from 100 to 150<sup>o</sup>F and saturation pressures of 500 to 7000 psia. The viscometer was also used to measure the viscosity of methane saturated water at 100<sup>o</sup>F with a saturation pressure from 100 to 1000 psia and undersaturation pressure ranges of 1000 to 7000 psia.

The results of this study indicate that the viscosity of water increases with an increase in saturation pressure even at low saturation pressures. Results also imply that the viscosity of undersaturated gas-water mixtures remains constant at pressures above the saturation pressure. The viscosity of methane saturated water shows an increase

of 8% at 100°F and 7000 psia as compared to the viscosity of pure water at these same conditions. At 150°F and saturation pressure of 7000 psia, the viscosity of methane saturated water shows an increase of 6.5% as compared to pure water.

## CHAPTER 7

### RECOMMENDATIONS

The data presented in this work are for pure water, methane systems. In the field, natural gas mixtures and brines are normally encountered. To extend the work, the following recommendations are made:

1. Brine should be used instead of water.
2. Natural gas should be used instead of methane because the composition of natural gas has an important role on the dissolved of gas in water.
3. The viscosity of gas saturated water above various saturation pressures should be considered.

Further, as indicated before, due to unavailability of data on the viscosity of methane saturated water, there are no data with which to compare results. So, I recommend that another type of viscometer be used to measure the viscosity of methane saturated water. A capillary viscometer should work if the pressures are maintained above saturation pressures.

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## NOMENCLATURE

C	=	Correction factor
d	=	Equivalent Diameter, cm
K	=	Calibration constant
MW	=	Molecular weight of methane
P1	=	Pressure, $\text{kg/cm}^2$
Ps	=	saturation pressure, psia
Rswb	=	Solubility of methane in brine, cu ft/bbl
Rsw	=	Solubility of methane in water, cu ft/bbl
S	=	Salinity, (g/g of solution) 100
S1	=	Salinity, ppm
T	=	Temperature, $^{\circ}\text{F}$
t	=	Roll time, sec
v	=	Velocity, cm/sec
$\rho$	=	Density, g/cc
$\mu$	=	Viscosity, cp

## APPENDIX A

TABLE : 4  
VISCOMETER CALIBRATION

FLUID: Pure Water		TEMPERATURE (°F) = 100		PRESSURE (psia) = 14.7	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND		
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°L</u>
20.44	12.66	10.27	20.4325	12.66	10.26
20.43	12.66	10.25			
20.42	12.66	10.26			
20.44	12.66	10.26			
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
7.7492	0.99307	6.75463	138.01390	85.51362	69.30250
					<u>CENTIPOISE</u>
					0.68009
Equation for the density of stainless steel 0.252 inch ball:					
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$					

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water		TEMPERATURE (°F) = 100		PRESSURE (psia) = 100	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND		
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
20.44	12.66	10.30	20.4425	12.65	10.26
20.42	12.65	10.24			
20.46	12.64	10.26			
20.45	12.65	10.24			
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
7.7492	0.99333	6.75587	138.10687	85.46176	69.31523
CENTIPOISE					
0.68009					
Equation for the density of stainless steel 0.252 inch ball:					
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$					

TABLE: 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
23°	45°	70°	23°	45°	70°	
20.46	12.66	10.25	20.445	12.665	10.25	
20.44	12.66	10.26				
20.45	12.67	10.25				
20.43	12.67	10.25				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY		DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
Ball	Fluid	DIFFERENCE	23°	45°	70°	CENTIPOISE
7.7492	0.99457	6.75463	138.09841	85.54739	69.23496	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 1000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.41	12.65	10.24	20.4075	12.6525	10.232	
20.40	12.65	10.23				
20.41	12.65	10.23				
20.41	12.66	10.23				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	.99611	6.75309	137.81368	85.4437	69.10099	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						



TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water		TEMPERATURE (°F) = 100		PRESSURE (psia) = 1500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND		
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
20.56	12.67	10.23	20.55	12.68	10.235
20.52	12.68	10.24			
20.56	12.67	10.24			
20.56	12.7	10.23			
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
7.7492	0.99762	6.75158	138.74497	85.61003	69.10242
					<u>CENTIPOISE</u>
					0.58009
Equation for the density of stainless steel 0.252 inch ball:					
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$					

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 2000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.51	12.64	10.23	20.483	12.663	10.233	
20.50	12.65	10.26				
20.46	12.68	10.21				
20.46	12.68	10.23				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	0.99913	6.75007	138.25831	85.47276	69.07009	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 2500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.52	21.71	10.24	20.528	12.698	10.248	
20.55	12.67	10.25				
20.53	12.72	10.24				
20.51	12.69	10.26				

DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY		DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.00061	6.74859	138.53168	85.69022	69.15618	0.68009

Equation for the density of stainless steel 0.252 inch ball:

$$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$$

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 3000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.49	12.67	10.23	20.50	12.67	10.225	
20.51	12.67	10.23				
20.50	12.66	10.22				
20.50	12.68	10.22				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.00208	6.74712	138.31596	85.48601	68.9893	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water		TEMPERATURE (°F) = 100		PRESSURE (psia) = 3500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND		
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
20.52	12.70	10.25	20.528	12.698	10.255
20.52	12.71	10.24			
20.55	12.68	10.27			
20.52	12.7	10.26			
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
7.7492	1.00353	6.74567	138.47174	85.65314	69.17685
					<u>CENTIPOISE</u>
					0.68009
Equation for the density of stainless steel 0.252 inch ball:					
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$					

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 4000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.56	12.74	10.28	20.598	12.733	10.275	
20.61	12.73	10.27				
20.60	12.71	10.28				
20.62	12.75	10.27				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME		VISCOSITY	
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.00496	6.74424	138.91448	85.87104	69.29707	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 4500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.60	12.71	10.26	20.573	12.71	10.258	
20.61	12.70	10.26				
20.54	12.71	10.26				
20.54	12.72	10.25				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.00638	6.74282	138.71666	85.70124	69.16448	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 5000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.55	12.70	10.25	20.545	12.7	10.25	
20.51	12.7	10.26				
20.56	12.68	10.24				
20.56	12.72	10.25				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY		DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.00777	6.74143	138.50268	85.61616	69.09966	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ °F}) \text{ g/cc}$						



TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 5500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.57	12.7	10.28	20.59	12.72	10.28	
20.58	12.72	10.28				
20.62	12.72	10.28				
20.59	12.74	10.28				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY		DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.00915	6.74005	138.77763	85.73344	69.28721	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 6000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.56	12.73	10.26	20.575	12.743	10.268	
20.57	12.74	10.27				
20.58	12.72	10.27				
20.59	12.78	10.27				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY X ROLL TIME		DENSITY DIFFERENCE	
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>VISCOSITY</u>
7.7492	1.01052	6.73869	138.64855	85.86776	69.1895	<u>CENTIPOISE</u> 0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 6500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.60	12.73	10.26	20.56	12.72	10.273	
20.54	12.71	10.27				
20.52	12.73	10.28				
20.58	12.71	10.28				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.01186	6.73734	138.51971	85.69896	69.20933	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 7000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.66	12.73	10.29	20.64	12.748	10.298	
20.62	12.75	10.30				
20.63	12.75	10.30				
20.65	12.76	10.30				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY		DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.01318	6.73602	139.03145	85.86741	69.36417	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ °F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 7500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.65	12.79	10.30	20.65	12.77	10.303	
20.66	12.78	10.30				
20.66	12.76	10.31				
20.63	12.75	10.30				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME		VISCOSITY	
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.01449	6.73471	139.07176	86.00225	69.38435	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 4 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 100		PRESSURE (psia) = 8000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
20.65	12.78	10.33	20.68	12.78	10.328	
20.69	12.78	10.32				
20.69	12.78	10.33				
20.69	12.78	10.33				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME		VISCOSITY	
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	1.01578	6.73342	139.24713	86.05311	69.53940	0.68009
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 14.7	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.76	9.84	8.17	14.7725	9.85	8.175	
14.79	9.85	8.17				
14.76	9.85	8.18				
14.78	9.86	8.18				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.98025	6.76655	99.95886	66.65052	55.31655	0.42859
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 100	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.79	9.85	8.18	14.785	9.855	8.18	
14.78	9.86	8.19				
14.79	9.85	8.17				
14.78	9.85	8.18				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.98052	6.76628	100.03945	66.68169	55.34817	0.42859
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						



TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.82	9.86	8.18	14.812	9.858	8.188	
14.82	9.85	8.19				
14.84	9.86	8.19				
14.78	9.86	8.19				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME		VISCOSITY	
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	.98176	6.76504	100.20377	66.68638	55.38877	0.42859
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 1000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.80	9.87	8.22	14.863	9.878	8.213	
14.92	9.88	8.21				
14.86	9.88	8.21				
14.87	9.88	8.21				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.9833	6.7635	100.52252	66.80647	55.54524	0.42859
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 1500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.82	9.89	8.20	14.83	9.888	8.21	
14.85	9.88	8.21				
14.82	9.9	8.22				
14.83	9.88	8.21				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.98482	6.76198	100.28016	66.85908	55.51586	0.42859
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 2000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.87	9.90	8.22	14.855	9.903	8.218	
14.88	9.91	8.21				
14.90	9.90	8.22				
14.89	9.90	8.22				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY		DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.98631	6.76049	100.62989	66.96051	55.56657	0.43
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 2500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.94	9.91	8.23	14.91	9.908	8.225	
14.89	9.90	8.22				
14.88	9.90	8.22				
14.93	9.92	8.23				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.98779	6.75901	100.77684	66.96489	55.59286	0.43
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water		TEMPERATURE (°F) = 150		PRESSURE (psia) = 3000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND		
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
14.90	9.91	8.22	14.915	9.91	8.225
14.90	9.90	8.22			
14.95	9.92	8.22			
14.91	9.91	8.24			
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
7.7468	0.98924	6.75756	100.78901	66.96742	55.58093
					<u>CENTIPOISE</u> 0.43
Equation for the density of stainless steel 0.252 inch ball:					
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$					

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 3500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.93	9.93	8.26	14.94	9.935	8.253	
14.95	9.94	8.25				
14.93	9.93	8.25				
14.95	9.94	8.25				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.99067	6.75613	100.93658	67.12215	55.75496	0.43082
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water		TEMPERATURE (°F) = 150		PRESSURE (psia) = 4000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND		
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
14.89	9.92	8.25	14.923	9.918	8.238
14.92	9.92	8.23			
14.94	9.92	8.23			
14.92	9.91	8.24			
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
7.7468	0.99208	6.75472	100.79731	66.98994	55.64201
					<u>CENTIPOISE</u> 0.43157
Equation for the density of stainless steel 0.252 inch ball:					
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$					



TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 4500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.95	9.97	8.29	14.985	9.963	8.28	
14.96	9.97	8.28				
15.00	9.96	8.28				
15.03	9.95	8.27				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME		VISCOSITY	
<u>Ball</u>	<u>Fluid</u>	<u>DENSITY</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.99347	6.75333	101.19865	67.28005	55.91757	0.43157
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continus)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 5000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.95	9.94	8.26	14.953	9.95	8.258	
14.97	9.95	8.25				
14.94	9.96	8.26				
14.95	9.95	8.26				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY		DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.99484	6.75196	100.95868	67.18200	55.75431	0.43231
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water		TEMPERATURE (°F) = 150		PRESSURE (psia) = 5500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND		
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
15.00	9.96	8.26	15.015	9.965	8.27
14.96	9.96	8.28			
15.00	9.97	8.27			
15.01	9.97	8.27			
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
7.7468	0.99619	6.75061	101.36041	67.26983	55.82754
					<u>CENTIPOISE</u> 0.43231
Equation for the density of stainless steel 0.252 inch ball:					
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$					

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 6000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
23°	45°	70°	23°	45°	70°	
14.99	9.99	8.27	15.003	9.973	8.278	
15.02	9.96	8.29				
14.99	9.96	8.28				
15.01	9.98	8.27				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME		VISCOSITY	
Ball	Fluid	DIFFERENCE	23°	45°	70°	CENTIPOISE
7.7468	0.99751	6.74929	101.25622	67.30729	55.86725	0.43306
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 6500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
14.98	10.00	8.29	15.0	9.99	8.285	
14.99	9.99	8.28				
15.00	9.99	8.28				
15.03	9.98	8.29				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	0.99881	6.74799	101.21985	67.41242	55.90710	0.43306
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 7000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
15.08	10.00	8.30	15.055	10.005	8.303	
15.08	10.00	8.30				
15.03	10.01	8.31				
15.03	10.01	8.30				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	1.00009	6.74671	101.57172	67.50083	56.01456	0.43380
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 7500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
15.04	10.03	8.32	15.058	10.025	8.32	
15.06	10.02	8.33				
15.07	10.02	8.32				
15.06	10.03	8.31				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME		VISCOSITY	
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	1.00135	6.74545	101.56961	67.62314	56.12214	0.43380
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 5 (continue)  
VISCOMETER CALIBRATION

FLUID: Pure Water			TEMPERATURE (°F) = 150		PRESSURE (psia) = 8000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
15.07	10.04	8.34	15.095	10.043	8.333	
15.08	10.04	8.33				
15.12	10.05	8.33				
15.09	10.04	8.33				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7468	1.00258	6.74422	101.80400	67.72883	56.19621	0.43380
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						



TABLE : 6  
VISCOMETER CALIBRATION

FLUID: n-Pentane		TEMPERATURE (°F) = 100		PRESSURE (psia) = 100	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND		
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
9.39	6.50	5.49	9.394	6.504	5.49
9.39	6.51	5.49			
9.39	6.51	5.50			
9.39	6.51	5.49			
9.41	6.49	5.48			
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>
7.7492	0.6059	7.1433	67.10416	46.46002	39.2167
<u>CENTIPOISE</u> 0.2085					
Equation for the density of stainless steel 0.252 inch ball:					
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$					

TABLE : 6 (continue)  
VISCOMETER CALIBRATION

FLUID: n-Pentane			TEMPERATURE (°F) = 100		PRESSURE (psia) = 500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
23°	45°	70°	23°	45°	70°	
9.49	6.57	5.53	9.49	6.57	5.53	
9.49	6.57	5.53				
9.48	6.57	5.53				
9.50	6.57	5.53				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME			VISCOSITY
Ball	Fluid	DIFFERENCE	23°	45°	70°	CENTIPOISE
7.7492	0.6891	7.1401	67.75955	46.91046	39.4848	0.2165
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 6 (continue)  
VISCOMETER CALIBRATION

FLUID: n-Pentane			TEMPERATURE (°F) = 100		PRESSURE (psia) = 1000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
9.60	6.65	5.59	9.6125	6.6425	5.5925	
9.62	6.64	5.60				
9.61	6.64	5.59				
9.62	6.64	5.59				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)			DENSITY DIFFERENCE X ROLL TIME		VISCOSITY	
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>CENTIPOISE</u>
7.7492	0.6128	7.1364	68.59865	47.40354	39.9103	0.2265

Equation for the density of stainless steel 0.252 inch ball:

$$\rho = 7.754 - (0.000048 \times T \text{ °F}) \text{ g/cc}$$

TABLE : 7  
VISCOMETER CALIBRATION

FLUID: n-Pentane			TEMPERATURE (°F) = 150		PRESSURE (psia) = 100	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u>	<u>45°</u>	<u>70°</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
8.51	5.97	5.06	8.518	5.97	5.0575	
8.52	5.97	5.06				
8.52	5.97	5.06				
8.53	5.97	5.05				
8.51						
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY	DENSITY DIFFERENCE X ROLL TIME		VISCOSITY	
<u>Ball</u>	<u>Fluid</u>	<u>DIFFERENCE</u>	<u>23°</u>	<u>45°</u>	<u>70°</u>	
7.7468	0.5782	7.1686	61.06213	42.79654	36.2552	
<u>CENTIPOISE</u> 0.1681						
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 7 (continue)  
VISCOMETER CALIBRATION

FLUID: n-Pentane			TEMPERATURE (°F) = 150		PRESSURE (psia) = 500	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u> 8.65	<u>45°</u> 6.04	<u>70°</u> 5.11	<u>23°</u> 8.64	<u>45°</u> 6.0450	<u>70°</u> 5.115	
8.64	6.05	5.11				
8.63	6.05	5.12				
8.64	6.04	5.12				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY		DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u> 7.7468	<u>Fluid</u> 0.5833	<u>DIFFERENCE</u> 7.1635	<u>23°</u> 61.89264	<u>45°</u> 43.30336	<u>70°</u> 36.6413	<u>CENTIPOISE</u> 0.1751
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

TABLE : 7 (continue)  
VISCOMETER CALIBRATION

FLUID: n-Pentane			TEMPERATURE (°F) = 150		PRESSURE (psia) = 1000	
ROLL TIME (SECOND)			AVERAGE ROLL TIME SECOND			
<u>23°</u> 8.76	<u>45°</u> 6.13	<u>70°</u> 5.19	<u>23°</u> 8.77	<u>45°</u> 6.1275	<u>70°</u> 5.19	
8.78	6.12	5.19				
8.77	6.13	5.18				
8.77	6.13	5.20				
DENSITY AT PRESSURE & TEMPERATURE (g/cc)		DENSITY		DENSITY DIFFERENCE X ROLL TIME		VISCOSITY
<u>Ball</u> 7.7468	<u>Fluid</u> 0.5875	<u>DIFFERENCE</u> 7.1593	<u>23°</u> 62.78706	<u>45°</u> 43.86861	<u>70°</u> 37.1568	<u>CENTIPOISE</u> 0.1845
Equation for the density of stainless steel 0.252 inch ball:						
$\rho = 7.754 - (0.000048 \times T \text{ } ^\circ\text{F}) \text{ g/cc}$						

## APPENDIX B

TABLE : 8  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100		PRESSURE (psia) = 500	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE	
		Ball	Fluid		
20.99	21.00	7.7492	0.99397	6.75522	
21.00					
21.03					
20.98					

\*VISCOSITY OF FLUID  
0.70098

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$



TABLE : 8 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 1000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
<u>21.34</u>	<u>21.33</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.75405</u>
21.33		7.7492	0.99515	
21.33				
21.32				

\*VISCOSITY OF FLUID  
0.71546

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 8 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 2000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
<u>21.43</u>	<u>21.4375</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.75207</u>
21.42		7.7492	0.99712	
21.45				
21.45				

\*VISCOSITY OF FLUID  
0.71996

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 8 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 3000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
		<u>Ball</u>	<u>Fluid</u>	
<u>21.45</u>	<u>21.42</u>	7.7492	0.99906	<u>6.75014</u>
21.40				
21.41				
21.42				
<u>*VISCOSITY OF FLUID</u>				
0.71891				

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_r) - 0.23128$$

TABLE : 8 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 4000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
		Ball	Fluid	
21.45	21.4325	7.7492	1.00082	6.74838
21.42				
21.44				
21.42				

\*VISCOSITY OF FLUID  
0.71921

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 8 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat Water		TEMPERATURE (°F) = 100		PRESSURE (psia) = 5000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE	
<u>21.46</u>	<u>21.475</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.74589</u>	
21.49		7.7492	1.00331		
21.47					
21.48					

\*VISCOSITY OF FLUID  
0.72075

\*Equation for viscosity at 23° 1s:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 8 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 6000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)	DENSITY DIFFERENCE	
		<u>Ball</u>	<u>Fluid</u>	
<u>21.45</u>	<u>21.4575</u>	<u>7.74</u>	<u>1.00429</u>	<u>6.74491</u>
21.44				
21.46				
21.48				

\*VISCOSITY OF FLUID  
0.71984

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 8 (continua)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100		PRESSURE (psia) = 7000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE	
<u>21.63</u>	<u>21.622</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.74322</u>	
21.62		7.7492	1.00598		
21.59					
21.63					
21.64					

\*VISCOSITY OF FLUID  
0.72689

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 8 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100		PRESSURE (psia) = 8000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE	
		<u>Ball</u>	<u>Fluid</u>		
<u>21.79</u>	<u>21.764</u>	7.7492	1.00766	<u>6.74154</u>	
21.74					
21.75					
21.78					
21.76					

\*VISCOSITY OF FLUID  
0.73294

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$



TABLE : 9  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 150	PRESSURE (psia) = 500	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)	DENSITY DIFFERENCE	
<u>14.83</u>	<u>14.812</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.766344</u>
14.83		7.7468	0.980456	
14.84				
14.85				
14.83				

\*VISCOSITY OF FLUID  
0.42736

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 9 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 150	PRESSURE (psia) = 1000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)	DENSITY DIFFERENCE	
<u>14.93</u>	<u>14.944</u>	<u>Ball</u> 7.7468	<u>Fluid</u> 0.981523	<u>6.76517</u>
14.94				
14.94				
14.95				
14.96				

\*VISCOSITY OF FLUID  
0.433111

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 9 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 150	PRESSURE (psia) = 2000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
<u>15.24</u>	<u>15.248</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.76316</u>
15.26		7.7468	0.983535	
15.25				
15.25				
15.24				

\*VISCOSITY OF FLUID  
0.44642

\*Equation for viscosity at 23° 1a:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 9 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 150	PRESSURE (psia) = 3000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
<u>15.24</u>	<u>15.258</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.76130</u>
15.27		7.7468	0.985393	
15.26				
15.26				

\*VISCOSITY OF FLUID  
0.44668

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 9 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 150	PRESSURE (psia) = 4000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
<u>15.30</u>	<u>15.3</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.75955</u>
15.32		7.7468	0.987142	
15.28				
15.30				
15.30				

\*VISCOSITY OF FLUID  
0.44837

\*Equation for viscosity at 23° 1a:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 9 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 150	PRESSURE (psia) = 5000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)	DENSITY DIFFERENCE	
<u>15.39</u>	<u>15.382</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.75791</u>
15.37		7.7468	0.988785	
15.38				
15.39				
15.38				
<u>*VISCOSITY OF FLUID</u>				
0.45184				

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 9 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 150	PRESSURE (psia) = 6000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
		Ball	Fluid	
15.44	15.426	7.7468	0.990390	6.75631
15.44				
15.41				
15.42				
15.42				
*VISCOSITY OF FLUID				
0.45364				

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 9 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 150	PRESSURE (psia) = 7000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
		Ball	Fluid	
15.52	15.514	7.7468	0.991933	6.75476
15.52				
15.51				
15.50				
15.52				

\*VISCOSITY OF FLUID  
0.45739

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$



TABLE : 9 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 150	PRESSURE (psia) = 8000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
<u>15.69</u>	<u>15.66</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.75324</u>
15.71		7.7468	0.993451	
15.70				
15.63				
15.60				

\*VISCOSITY OF FLUID  
0.46371

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 10  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100		PRESSURE (psia) = 500	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE	
		<u>Ball</u>	<u>Fluid</u>		
<u>21.20</u>	<u>21.202</u>	<u>7.7492</u>	<u>0.99398</u>	<u>6.75522</u>	
21.22					
21.17					
21.22					

\*VISCOSITY OF FLUID  
0.70994

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 10 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Sat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 1000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)	DENSITY DIFFERENCE	
<u>21.28</u>	<u>21.2775</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.75405</u>
21.27		7.7492	0.99515	
21.27				
21.29				

\*VISCOSITY OF FLUID  
0.71313

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 10 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Udsat. Water TEMPERATURE (°F) = 100		PRESSURE (psia) = 1500		
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)	DENSITY DIFFERENCE	
<u>21.28</u>	<u>21.258</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.75336</u>
21.24		7.7492	0.99584	
21.25				
21.27				
21.25				

\*VISCOSITY OF FLUID  
0.71217

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 10 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Udsat. Water TEMPERATURE (°F) = 100		PRESSURE (psia) = 2000		
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
<u>21.27</u>	<u>21.267</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.75267</u>
21.22		7.7492	0.99653	
21.29				
21.29				

\*VISCOSITY OF FLUID  
0.71247

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 10 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Udsat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 3000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)	DENSITY DIFFERENCE	
<u>21.26</u>	<u>21.25</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.75128</u>
21.24		7.7492	0.99722	
21.22				
21.28				

\*VISCOSITY OF FLUID  
0.71153

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 10 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Udsat. Water TEMPERATURE (°F) = 100		PRESSURE (psia) = 4000		
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
<u>21.21</u>	<u>21.1875</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.74989</u>
21.17		7.7492	0.99932	
21.19				
21.18				

\*VISCOSITY OF FLUID  
0.70856

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 10 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Udsat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 5000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
		Ball	Fluid	
21.20	21.2125	7.7492	1.00141	6.74779
21.19				
21.22				
21.24				

\*VISCOSITY OF FLUID  
0.70938

\*Equation for viscosity at 23° is:

$$= 0.0065717 \ t( \ b - \ f ) - 0.23128$$



TABLE : 10 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Undsat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 6000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)		DENSITY DIFFERENCE
<u>21.19</u>	<u>21.2025</u>	<u>Ball</u>	<u>Fluid</u>	<u>6.74708</u>
21.21		7.7492	1.00211	
21.22				
21.19				

\*VISCOSITY OF FLUID  
0.70875

\*Equation for viscosity at 23° 1a:

$$\mu = 0.0065717 \ t(\rho_b - \rho_f) - 0.23128$$

TABLE : 10 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Udsat. Water		TEMPERATURE (°F) = 100	PRESSURE (psia) = 7000	
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)	DENSITY DIFFERENCE	
<u>21.22</u>	<u>21.205</u>	<u>Ball</u> 7.7492	<u>Fluid</u> 1.00352	<u>6.74568</u>
21.16				
21.21				
21.23				

\*VISCOSITY OF FLUID  
0.70875

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \tau(\rho_b - \rho_f) - 0.23128$$

TABLE : 10 (continue)  
VISCOSITY OF FLUID

FLUID: CH <sub>4</sub> Udsat. Water TEMPERATURE (°F) = 100		PRESSURE (psia) = 8000		
ROLL TIME (SECOND)	AVERAGE ROLL TIME SECOND	DENSITY AT PRESSURE AND TEMPERATURE (g/cc)	DENSITY DIFFERENCE	
<u>21.22</u>	<u>21.19</u>	<u>Ball</u>	<u>Fluid</u>	<u></u>
21.20		7.7492	1.00493	6.74426
21.17				
21.17				

\*VISCOSITY OF FLUID  
0.70788

\*Equation for viscosity at 23° is:

$$\mu = 0.0065717 \ t(\rho_D - \rho_F) - 0.23128$$